DTIC FILE COPY

(4)

R-929

NCEL
Technical Report

February 1990

By C. A. Kodres

Sponsored By U.S. Naval Observatory

AD-A221 746

DENSITY PERTURBATIONS IN THE ATMOSPHERE ABOVE THE NAVAL OBSERVATORY INDUCED BY HEAT TRANSFERRED OFF UPWIND BUILDINGS

ABSTRACT The U.S. Naval Observatory is faced with a growing problem. Heat rejection by large buildings constructed adjacent to the Observatory is distorting the properties of the atmosphere. This distortion refracts the incoming light in an anomalous manner, introducing uncorrectable errors into celestial observations.

A building heats the atmosphere through the discharge of the heating and air conditioning systems and also by means of heat convected off hot walls and roof. As the air is heated, its physical properties are changed. This heating is heterogeneous, influenced by the geometry of the buildings and by the turbulence of the air. The perturbed atmosphere then rises due to the buoyancy of the heated air and is swept downwind toward the Observatory.

The energy transferred from the buildings to the air and the resulting change in the properties of the atmosphere were examined theoretically. Building heat rejection was significant, particularly in the late afternoon and early evening, throughout the year. Heat rejection rates of 5 MW for a large building are typical. When an entire street is included, an anomalous telescope error of up to 0.3 seconds of arc is predicted.

NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043-5003

METRIC CONVERSION FACTORS

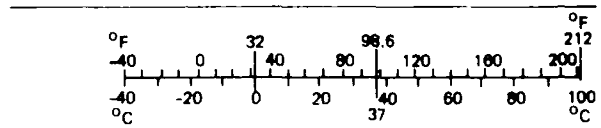
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10 286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-018

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
February 1990

3. REPORT TYPE AND DATES COVERED
Final; May 1987 to July 1989

4. TITLE AND SUBTITLE
DENSITY PERTURBATIONS IN THE ATMOSPHERE ABOVE THE NAVAL OBSERVATOR INDUCED BY HEAT TRANSFERRED OFF UPWIND BUILDINGS

5. FUNDING NUMBERS
PR - 71-051
WU - DN668101

6. AUTHOR(S)
C.A. Kodres

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSE(S)
Naval Civil Engineering Laboratory
Port Hueneme, CA 93043-5003

8. PERFORMING ORGANIZATION REPORT NUMBER
TR - 929

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESSE(S)
U.S. Naval Observatory
34th and Massachusetts Avenue, NW
Washington, DC 20392-5100

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

ABSTRACT The U.S. Naval Observatory is faced with a growing problem. Heat rejection by large buildings constructed adjacent to the Observatory is distorting the properties of the atmosphere. This distortion refracts the incoming light in an anomalous manner, introducing uncorrectable errors into celestial observations.

A building heats the atmosphere through the discharge of the heating and air conditioning systems and also by means of heat convected off hot walls and roof. As the air is heated, its physical properties are changed. This heating is heterogeneous, influenced by the geometry of the buildings and by the turbulence of the air. The perturbed atmosphere then rises due to the buoyancy of the heated air and is swept downwind toward the Observatory.

The energy transferred from the buildings to the air and the resulting change in the properties of the atmosphere were examined theoretically. Building heat rejection was significant, particularly in the late afternoon and early evening, throughout the year. Heat rejection rates of 5 MW for a large building are typical. When an entire street is included, an anomalous telescope error of up to 0.3 seconds of arc is predicted.

14. SUBJECT TERMS
Thermal pollution; astrometry; celestial navigation, observational error, light refraction, anamolous refraction, building heat rejection, building wall simulation, building model

15. NUMBER OF PAGES
65

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

CONTENTS

Page

INTRODUCTION

The U.S. Naval Observatory is faced with a growing problem. Heat rejection by large buildings constructed adjacent to the Observatory is distorting the physical properties of the lower atmosphere. This distortion refracts (bends) the incoming light in an anomalous manner, introducing uncorrectable errors into celestial observations.

The distortion of the atmosphere is very small. However, a primary mission of the Naval Observatory is to determine and maintain a sophisticated celestial reference system for such applications as satellite navigation, missile guidance systems, stellar tracking systems, and satellite station keeping. Navigational errors of even fractions of a second of arc are not tolerable. The problem is discussed in detail in Appendix A.

A building heats the atmosphere in two ways. Energy is transferred to the atmosphere with the discharge of heating and air conditioning systems (HVAC). Buildings also heat the air by convection heat transfer off their walls. During the morning and early afternoon, the walls receive more solar radiation than can be conducted into the building or can be transferred to the wind, and the walls heat up. In the late afternoon and early evening, the temperature of the air decreases, and large temperature gradients exist between the still hot walls of the building and the surrounding atmosphere. The stored energy is then convected to the air blowing over these walls at a rate proportional to this temperature gradient and to the velocity of the wind.

As the air is heated, its physical properties are changed. This heating is heterogeneous, influenced by the geometry of the buildings and by the turbulence of the air. The perturbed atmosphere rises due to the buoyancy of the heated air and is swept downwind (e.g., toward the Observatory).

The problem can be summarized as a sequence of four elements:

1. Buildings are heated by the sun and internal energy consumption, and, in general, the amount of energy involved is proportional to the size of the building.

2. A hot building emits "heat," and this, in conjunction with the wind, changes the downwind structure of the atmosphere.

3. A perturbed atmosphere changes the direction of travel of incoming (star) light in an unpredictable way, and this changes observed (star) positions.

4. An additional error is thus introduced into the observations, and this adversely affects the accuracy of sophisticated navigation systems.

The solution to this problem is to restrict the size of buildings constructed upwind of the Observatory. To accomplish this, the Navy petitioned the District of Columbia Zoning Commission to establish a "precinct district" in the neighborhood immediately surrounding the Observatory. Within this district, the height of future construction would be limited.

The Zoning Commission was not to be convinced by qualitative arguments, however. Numbers were required. They would insist on knowing: How much error is being introduced into the observations?

Property changes of such small magnitudes occurring over regions of several hundred yards are very difficult to measure. Instead, the severity of the problem was ascertained theoretically. The first two elements, energy transferred from the buildings to the air and the resulting change in the structure of the atmosphere, were examined by the Naval Civil Engineering Laboratory (NCEL). Using density as the measure of structure, a parametric study was conducted, varying building size and location, number of buildings, wall construction, time of day, time of year, and the direction of the wind. This report discusses the methods used by NCEL to make this study and presents the results.

GEOGRAPHY OF THE SITE

The Naval Observatory is located on a 72-acre site in northwest Washington, DC. The grounds are circular, with a 300-meter radius, as illustrated schematically on Figure 1.

The telescopes being threatened, the transit circle telescope and 26-inch refracting telescope, are located approximately in the center of the grounds. Figures 2 and 3 show the inside and outside of the transit house. This is the telescope of major concern. It is used for the fundamental star position work conducted at the Observatory. This telescope is mounted so that it can only observe along one meridian, i.e., the telescope can only look to the north and the south. Stars and planets are observed as they "transit" that meridian. Weather permitting, observations are made 24 hours a day throughout the year.

The 26-inch refracting telescope is the largest telescope at the Naval Observatory. It is primarily used for observing multiple star systems. Figure 4 shows the refractory telescope.

Wisconsin Avenue passes just west of the Observatory grounds, running approximately north-south; see again Figure 1. It is the development along this street that is the concern of the Observatory, in particular, the portion of Wisconsin Avenue that runs along the northwest perimeter of the Observatory. Development to the southwest is already proceeding.

There are no buildings on the western side of the Observatory grounds. Wisconsin Avenue and the telescopes are at about the same altitude. In between, the terrain drops down some 15 meters (40 or 50 feet) forming a little valley. The buildings housing the telescopes sit on a small hill. The western slope of this hill is thickly covered with trees (Figure 5). Foliage on the rest of the grounds is moderate (see Figures 6 and 7).

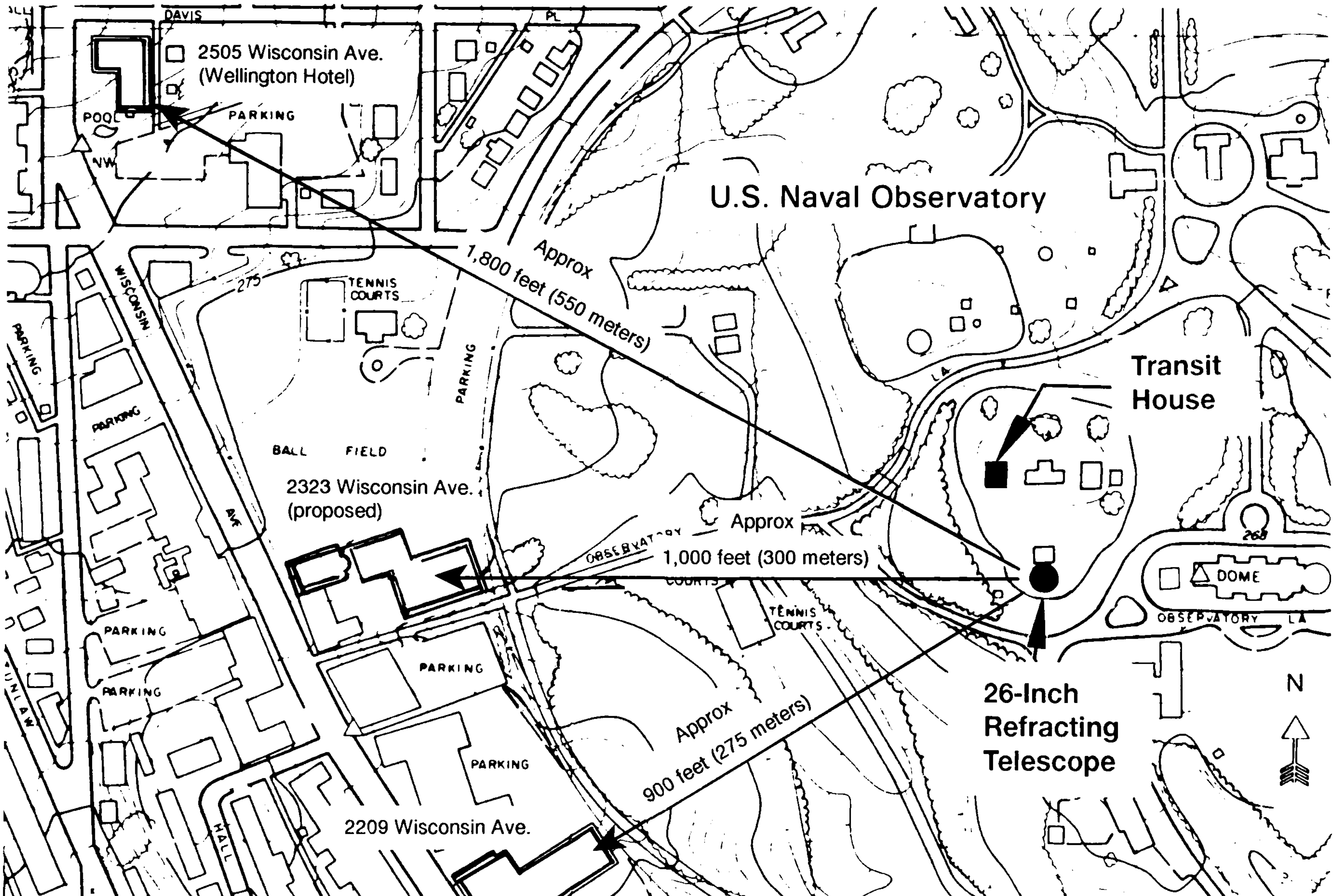


Figure 1. Schematic of NW Washington, DC showing the Naval Observatory and surroundings.

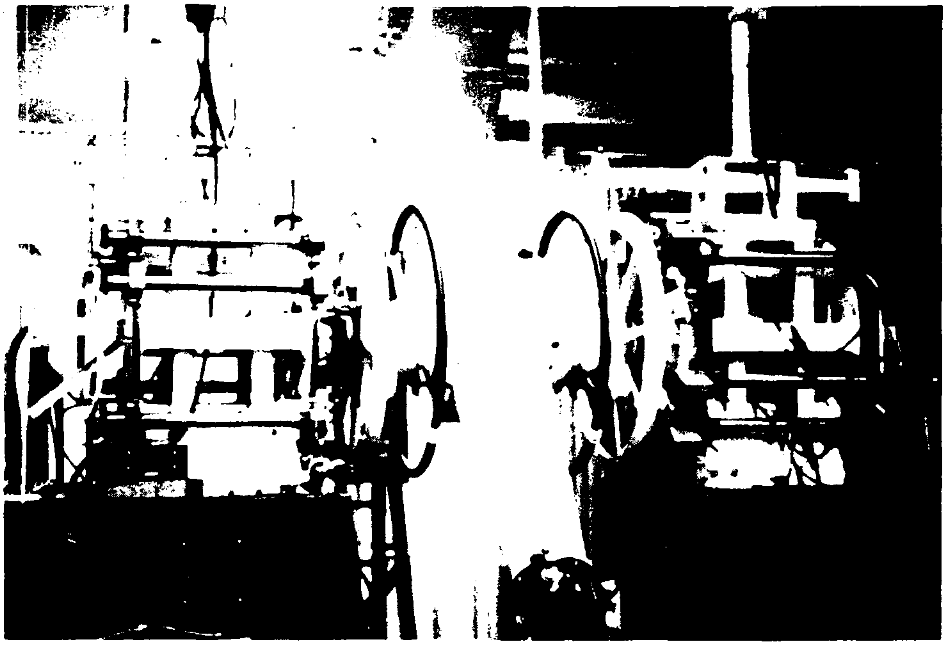


Figure 2. Inside of Transit House at the Naval Observatory.

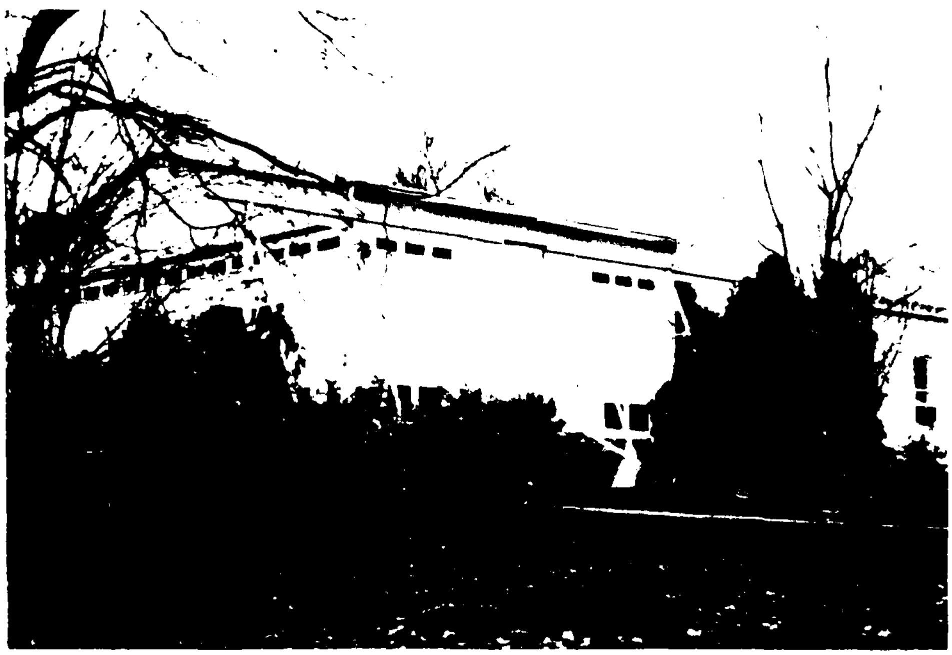


Figure 3. Outside the Transit House.

Figure 4. The 26-inch refracting telescope used at the Naval Observatory.

Figure 5. Looking back towards the woods covering the western slope of hill where the telescopes are located.

Figure 6. Looking from the Transit House back toward Wisconsin Avenue.

Figure 7. Looking from Wisconsin Avenue toward the Transit House.

CLIMATE OF THE SITE

Ambient air temperatures during a Washington, DC day in January and July were acquired from References 1 and 2. They are plotted along with the wall temperatures on many of the figures included with this report.

In January, the mean resultant surface wind is from the northwest at 7 mph; in July it is from the southwest at 4 mph. The wind direction and velocity will be used as parameters in this study. Construction of concern to the Naval Observatory is to their west. These analyses concentrate on winds approaching from that general direction. Two wind velocities were examined: 2 m/sec (4.5 mph) and 5 m/sec (11 mph).

BUILDING HEAT REJECTION

A building can heat the air in two ways, discharge from the HVAC and convection heat transfer off the walls. HVAC discharge, air conditioning or heating, depends upon the structure of the building, its function, people inside, and the weather. Calculating HVAC loads is straightforward, albeit tedious. It involves bookkeeping all the above variables and conducting mass and energy balances into and throughout the building. Several personal computer programs are available to do this bookkeeping. NCEL used the Elite Software Commercial HVAC energy estimation and load calculation program (Ref 3).

The role that convection plays in heating the air is best explained by example. Figure 8 is a schematic showing a cross section of a building wall. The arrows represent the different forms of energy arriving at and leaving the wall: solar radiation, radiation from the wall to the surroundings, conduction through the wall, and convection from the wall to the air. (Conduction and convection can be in either direction.) Applying conservation of energy to the outer section of the wall (brick),

> Solar radiation + Conduction from inside the building - Radiation to the surroundings - Convection to the air = Increase in the internal thermal energy of the wall

Note that this relationship is transient. Solar radiation is changing with time. The temperature of the air is also changing with time; therefore, convection and radiation off the wall are continually changing. Note also that it is one dimensional. Heat conduction along the walls is not included.

Conservation of energy of the wall can be expressed in mathematical form. For the brick (see Figure 8):

$$\rho C_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2} \qquad (1)$$

$$T = T_\infty \text{ for } t \leq 0$$

$$k \frac{\partial T}{\partial x} = \alpha \dot{q}_{solar} - h (T - T_\infty) - \varepsilon \sigma T^4 \text{ at } x = 0$$

$$T = T_{ins} \text{ at } x = \ell$$

$$k \frac{\partial T}{\partial x} = k_{ins} \frac{\partial T_{ins}}{\partial x} \quad \text{at } x = \ell$$

where: T = temperature

ρ = density

k = thermal conductivity

C_p = specific heat

ℓ = thickness

ε = emissivity

α = absorptivity

of the brick, and

t = time

x = length variable

h = convective film coefficient

$\dot{q}_{solar}$ = incident solar radiation

σ = Stefan-Boltzmann constant

T_∞ = air temperature

T_{ins} = temperature of wall insulation

with equivalent relationships for the insulation and the inside of the wall, resulting in four coupled, non-linear partial differential equations. Equations (1) were solved numerically, using a finite difference program developed at the NCEL and described in Appendix B. The program includes a geometric analysis that takes the angle of the sun's rays and the shading imposed by the angle of the rays into consideration. Finite subdivisions of the wall, used for these analyses, are shown on Figure 8. The temperature of the outer surface of the brick, designated T_{skin}, is the wall temperature referred to in this report.

Figure 9 was developed using this program. It shows the hourly variation of temperature of the wall illustrated on Figure 8, assuming a January day in Washington, DC. Early in the morning, air and wall temperatures are approximately equal. As the sun rises, the building begins to receive solar radiation, and the outer surface of the walls start to heat up. As the inside of the building is heated, energy is conducted through the wall insulation toward the outer surface, also tending to increase temperature.

The wall temperature is now slightly higher than the temperature of its surroundings. There is some convection from the walls to the air, but of much smaller magnitude than the incoming solar radiation, and the wall temperature continues to increase. Heat is still being conducted through the insulation toward the outer part of the walls. Radiation from the walls to its surroundings is negligible*.

*Building walls never get hot enough to re-radiate a significant proportion of the absorbed solar radiation.

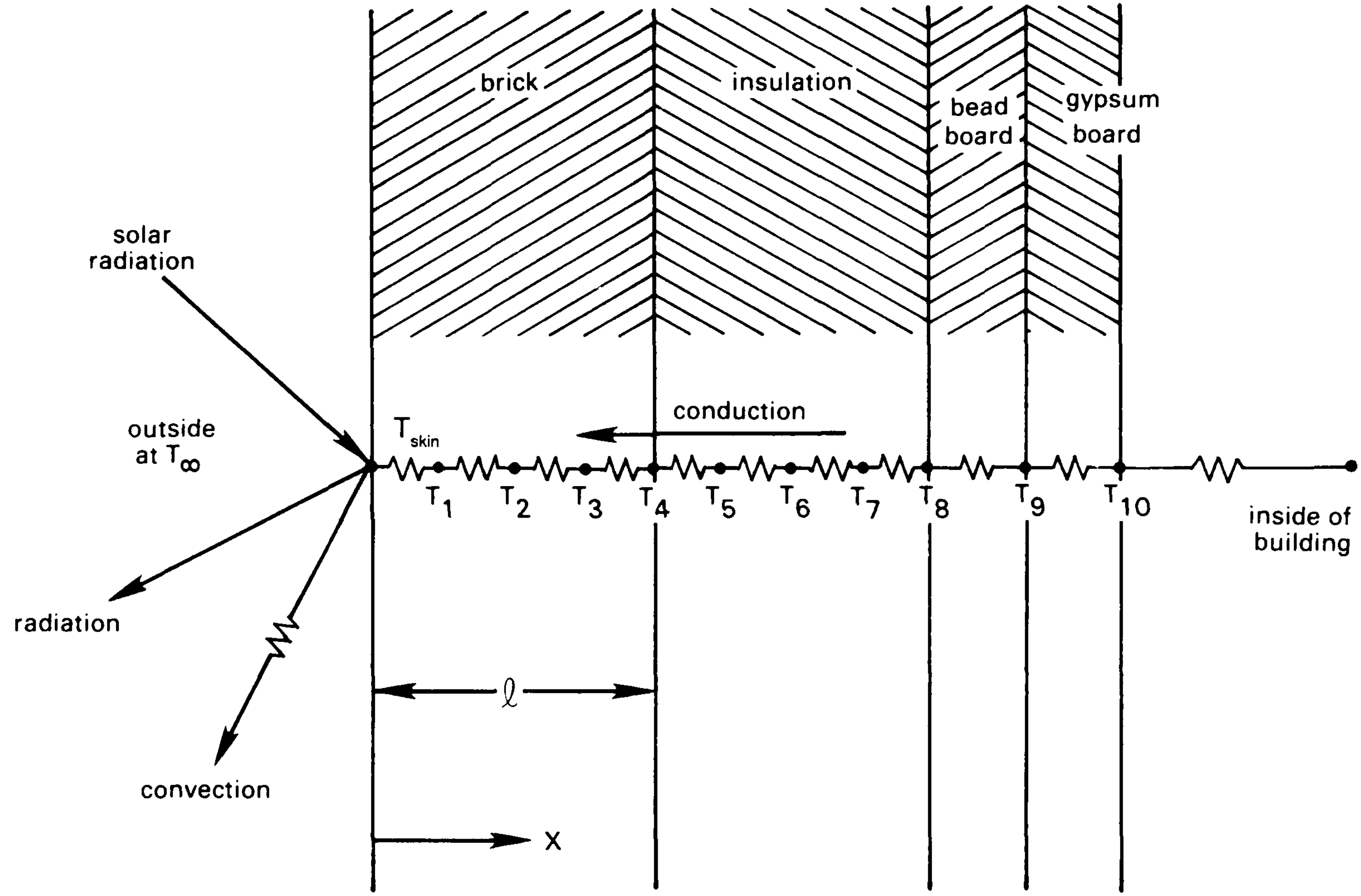
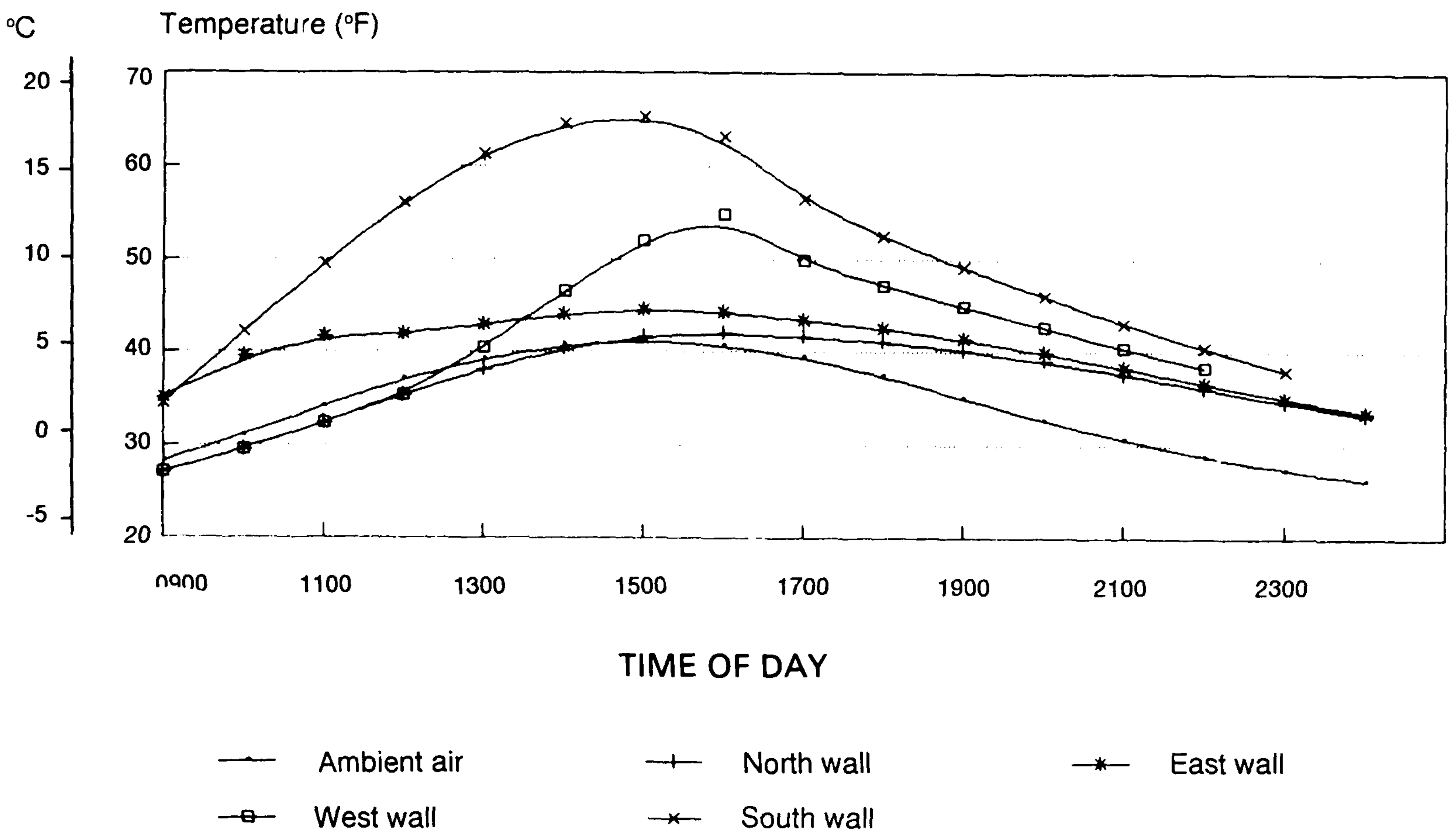


Figure 8. Cross-section of building wall.



NOTES: (1) Heavy wall construction
(2) Wind velocity = 2 m/sec (4.5 mph)
(3) Absorptivity = 0.7

Figure 9. Building wall temperatures for a January day in Washington, DC.

Sometime in the middle of the afternoon, the wall temperatures reach a maximum and begin to decrease. Convection off the walls is now exceeding the absorbed solar radiation plus whatever heat is being conducted out of the building. The air temperature starts to decrease at about this same time accelerating convection heat transfer off the walls.

As night approaches, solar radiation ceases, but heat convection continues. The wall temperature continues to fall, retarded slightly by the small amount of heat conducted out of the building. Finally, the building's heat is shut off, only convection remains, and the wall temperature decreases on down toward ambient. The next day, the cycle is repeated.

The situation is analogous in the summer with one difference. The inside of the building would normally be cooler than the outside part of the wall. Heat would thus be conducted into the building.

It is the energy convected from the walls to the air that is of interest here. Convection is represented mathematically in Equations (1) by the second term in the boundary condition at $x = 0$,

$$\text{Convection heat transfer} = h\,(T_{skin} - T_{\infty}) \qquad (2)$$

Note that convection is proportional to the difference between the wall temperature and the temperature of the air. Consequently, the difference between the wall temperature curves and the ambient temperature curve on Figure 9 provides an indication of the rate of convection heat transfer to the air. Even as late as midnight, the walls are heating the air. The other factor is the film coefficient, h. This factor varies with the properties of the air and its velocity. Since air properties remain nearly constant,

$$h \sim V^{n}$$

For most wind velocities encountered, $n \approx 0.8$. Experimentally fitting the constant of proportionality for air (Ref 2),

$$h = 0.5\ V^{0.78} \qquad (3)$$

Variables Affecting Convection Off Building Walls

A study of the heat convected off the walls of buildings, therefore, is a study of the variables affecting wall temperature and the variables affecting the film coefficient. In order to make such a study, a baseline configuration was established. This configuration is defined by Figures 8 and 10 and Tables 1 and 2 for the walls and roof.

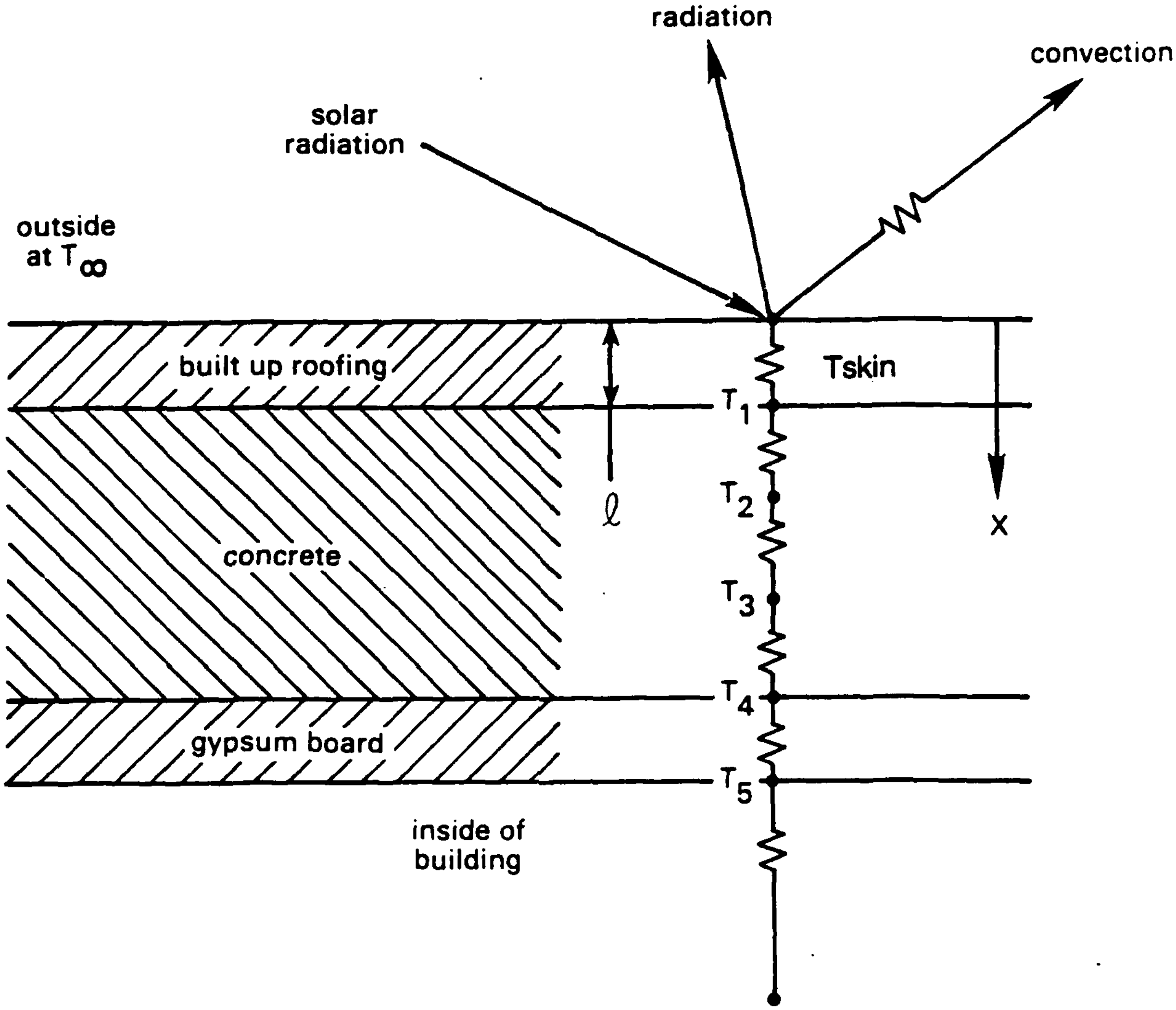


Figure 10. Cross-section of building roof.

Table 1. Properties of a Wall

Material	Thickness (cm)	Density (kg/m^3)	Specific Heat (J/kg-°C)	Thermal Conductivity (W/M - °C)
Brick	10.0	1922	840	0.7
Insulation	10.0	91	840	---
Bead Board	0.75	800	840	---
Gypsum Board	0.5	800	1090	0.4

Table 2. Properties of a Roof

Material	Thickness (cm)	Density (kg/m^3)	Specific Heat (J/kg-°C)	Thermal Conductivity (W/M - °C)
Roofing	0.9	990	1300	---
Concrete	30.5	2080	880	0.9
Gypsum Board	1.6	800	1090	0.4

There are two general variables: the construction of the wall and the climate/weather. Three outer wall construction configurations were examined. They are classified as heavy, medium, and light according to their heat capacity (density x specific heat x thickness). The baseline wall (brick) is classified as heavy. Table 3 gives examples of the three classifications.

Figure 11 shows the west wall temperature variation during a July day with outer wall construction as a parameter. As would be expected, the light wall heats up and cools off rapidly. Convection off this type of wall would be very high in the afternoon, low in the evening and negligible at night. Observe the change in the difference between the wall temperature and air (ambient) temperature. The high heat capacity brick wall heats up slowly, but there is still convection off this wall far into the night.

Table 3. Wall Classification

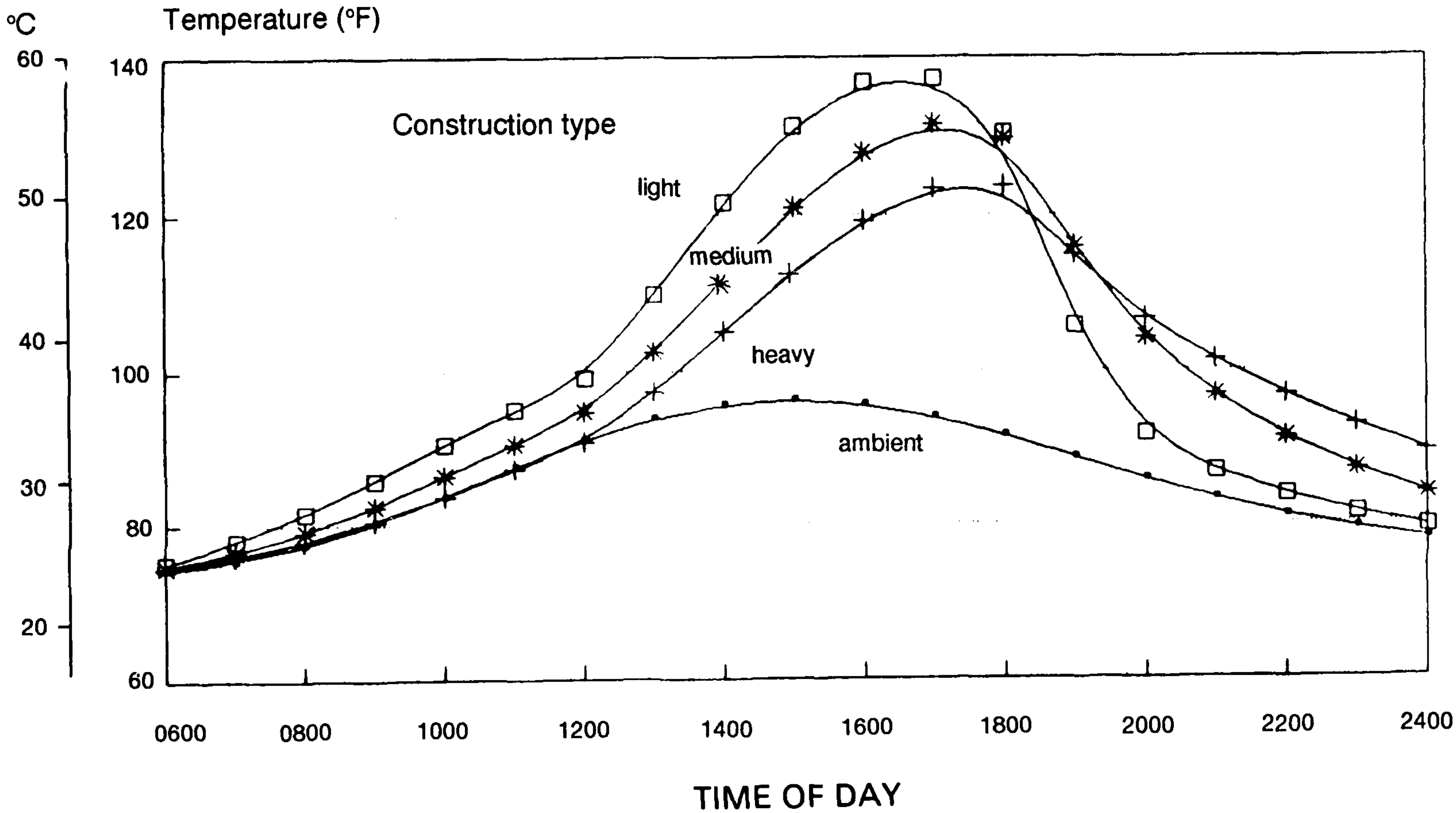
Class	Example	Density (kg/m^3)	Thickness (cm)	Specific Heat (J/kg·°C)	Heat Capacity* (J/m^2-°Cx10^{-4})
Heavy	10 cm brick	1922	10	840	16.4
Medium	Lightweight concrete	961	10	840	8.1
Light	Metal siding	7690	0.6	420	2.0

*Density x Specific Heat x Thickness

In Figure 11 it is assumed that all three walls absorb the same amount of solar radiation. This is not normally true. A brick wall, for example, might absorb twice as much of the incident solar radiation as a wall with metal siding. Absorptivity is a measure of this; it is defined as the fraction of radiation striking a surface that is absorbed by the material. Typical values are shown on Table 4. It follows that a wall with a high absorptivity will heat up faster. Figure 12 illustrates the effect of absorptivity on building wall temperature.

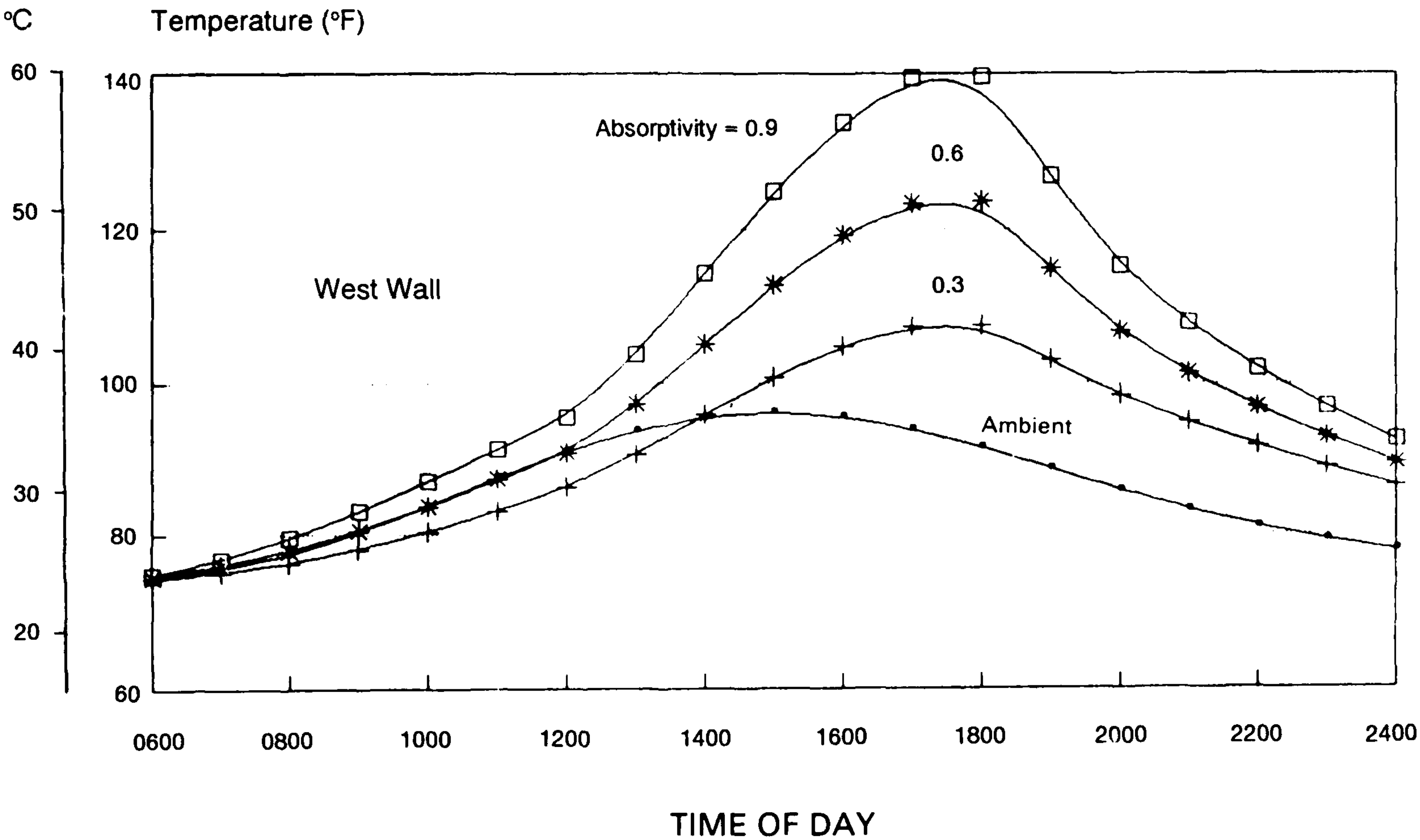
Table 4. Values of Absorptivity at Solar Wavelengths (Ref 10)

Material	Absorptivity
Asphalt	0.93
Roofing tile, brown	0.91
Slate composition	0.90
Red brick, red paint	0.70
Concrete	0.60
White enameled steel	0.50
White marble	0.45
Yellow paint	0.35
Aluminum, polished plate	0.29
Plaster	0.28



NOTES: (1) Wind velocity = 2 m/sec (4.5 mph)
(2) Absorptivity = 0.6
(3) Overall wall resistance = 0.6 m^2 - °C/kJ

Figure 11. Effect of the construction on the west wall temperature on a Washington, DC building in July.



NOTES: (1) Heavy type wall construction
(2) Wind velocity = 2 m/sec (4.5 mph)
(3) Overall wall resistance = 0.6 m^2 - °C/kJ

Figure 12. Effect of wall absorptivity on west wall temperature of a Washington, DC building in July.

When the wall is hotter than the inside of the building, heat is conducted toward the inside of the wall. The outer surface of the wall, therefore, cools off. Note the location of the insulation on Figure 8. Changing the resistance of this insulation should change the outer wall temperature. It does, as shown on Figure 13, but very little.

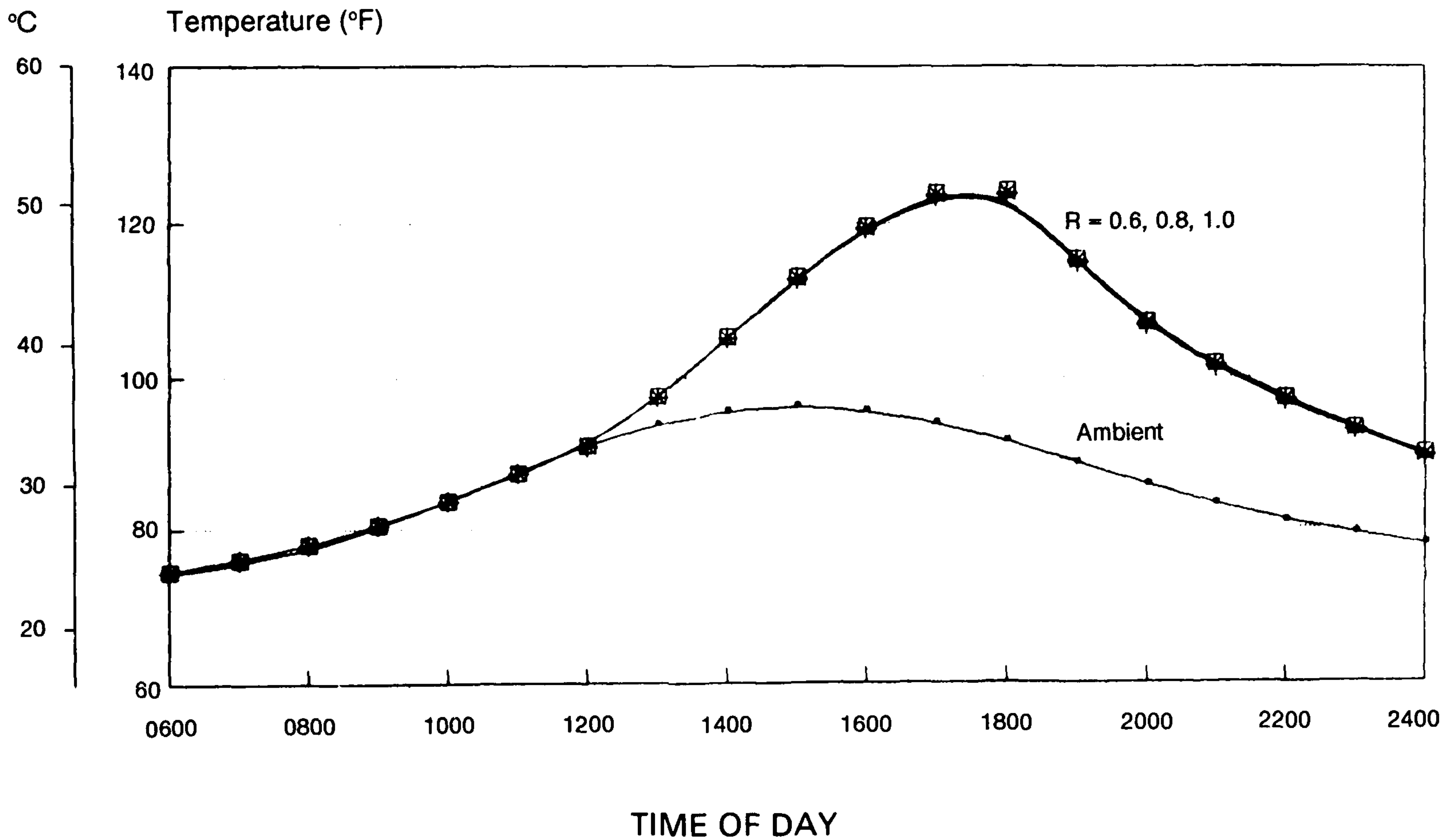
If density perturbations in the air are used as a measure, a "good" wall is a cool wall, particularly in the evening and at night. Heat convected to the air would then be minimum. A re-examination of Figures 11, 12 and 13 suggests that a good wall should be of light construction and low absorptivity. Wall resistance seems to have little effect. Figure 14 compares the two extremes, combining all the "good" wall properties and then all the "bad" properties, using the west wall as a vehicle. Temperatures of the various sides and roof of the buildings represented by these two extremes are plotted separately on Figures 15 and 16.

Climate and weather are not controllable variables, but they, nevertheless, affect the rate that heat is convected from the walls of a building to the surrounding air. The velocity of the wind is used as a parameter on Figure 17. Recall from the discussions of Equations (2) and (3) that the rate of convection off a flat surface is proportional to both the wind velocity and the difference between the wall and the air temperature. Plots such as Figure 9, therefore, only tell half the story. Given the same temperatures, the energy convected to the air on a windy day might be several times the energy convected on a calm day.

Consider Figure 17. The incident solar radiation and the absorptivity are kept constant. Consequently, the energy absorbed during the day is the same for all conditions examined, i.e., regardless of the wind velocity. It follows that the total energy convected to the air over 24 hours is also independent of the wind velocity.

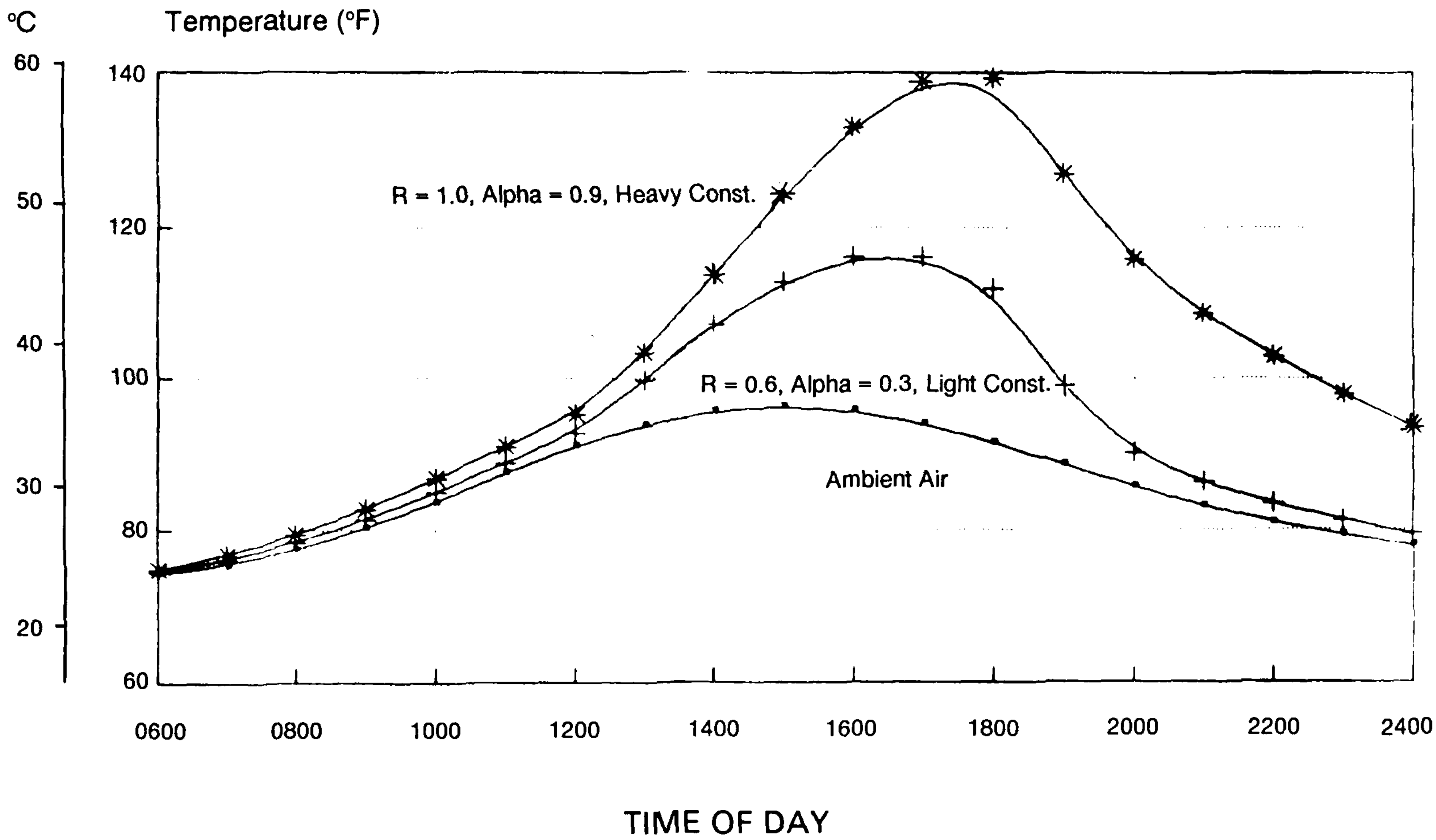
The windier the morning, the slower the walls heat up. Much of the solar energy absorbed by the walls is being immediately convected off to the wind. Less energy is being stored in the walls, however, and the heat convected to air during the rest of the day and night is small. Conversely, if the air is calm, little energy is convected to the wind. The incident solar radiation is stored in the walls as internal thermal energy, and the walls heat up. It is eventually convected out to the wind, but it takes a long time, into the evening and possibly far into the night.

If the evening and night are the time of greatest concern, the worst condition occurs when a calm day is followed by a windy evening and night. Wall temperatures build up during the day, and the stored energy is convected off at high rates during the night. The curve marked 0/2 on Figure 17 illustrates this possibility. The day is calm until 7 pm; at this time, a 2 m/sec (4.5 mph) wind starts up and continues to blow throughout the night. The film coefficient is the same as for the "2 m/sec" curve beneath it, but the temperature gradients are about twice as great.



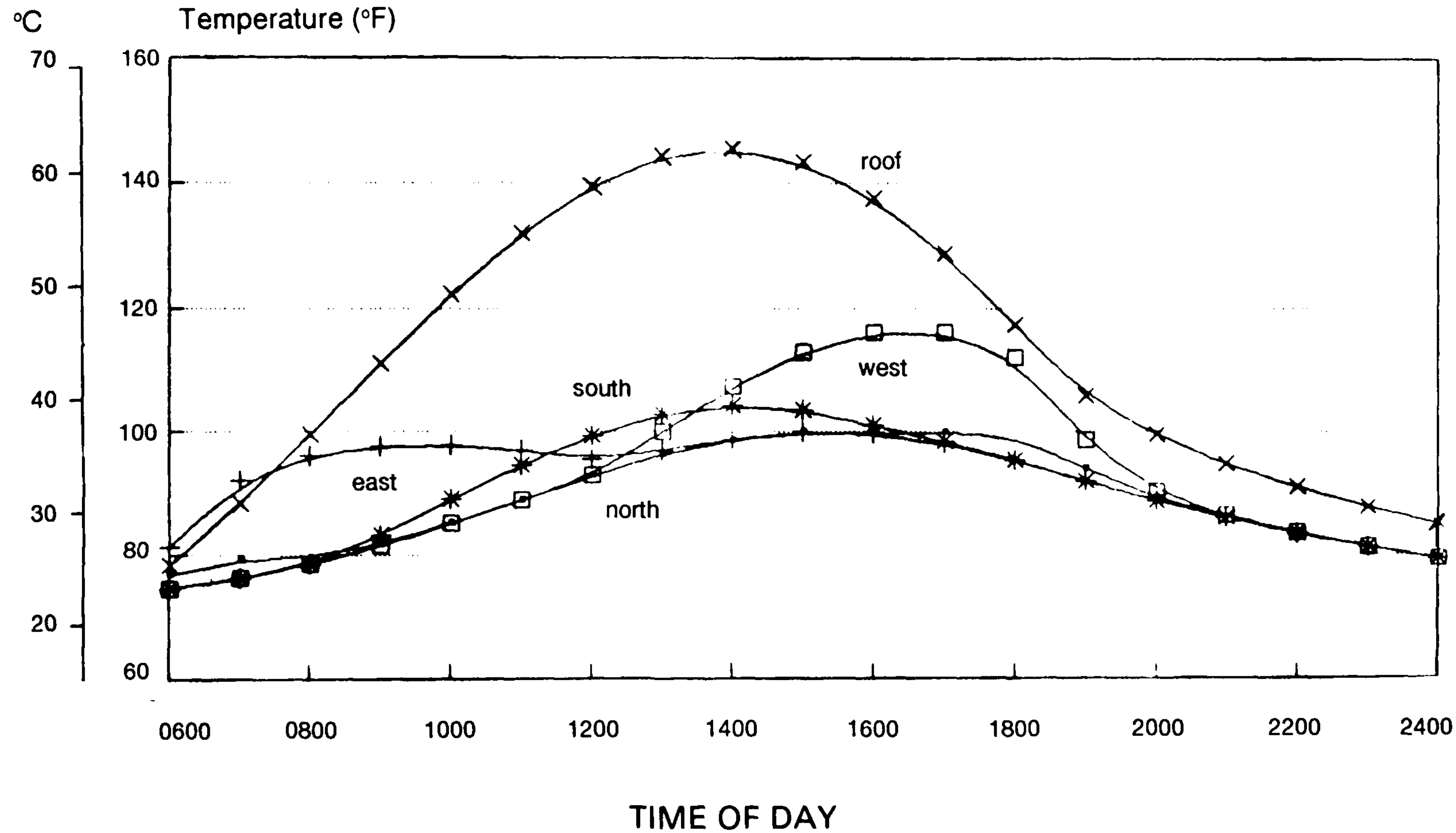
NOTES: (1) Heavy type wall construction
(2) Wind velocity = 2 m/sec (4.5 mph)
(3) Absorptivity = 0.6

Figure 13. Effect of the overall wall resistance (m^2 - °C/kJ) on the west wall temperature of a Washington, DC building in July.



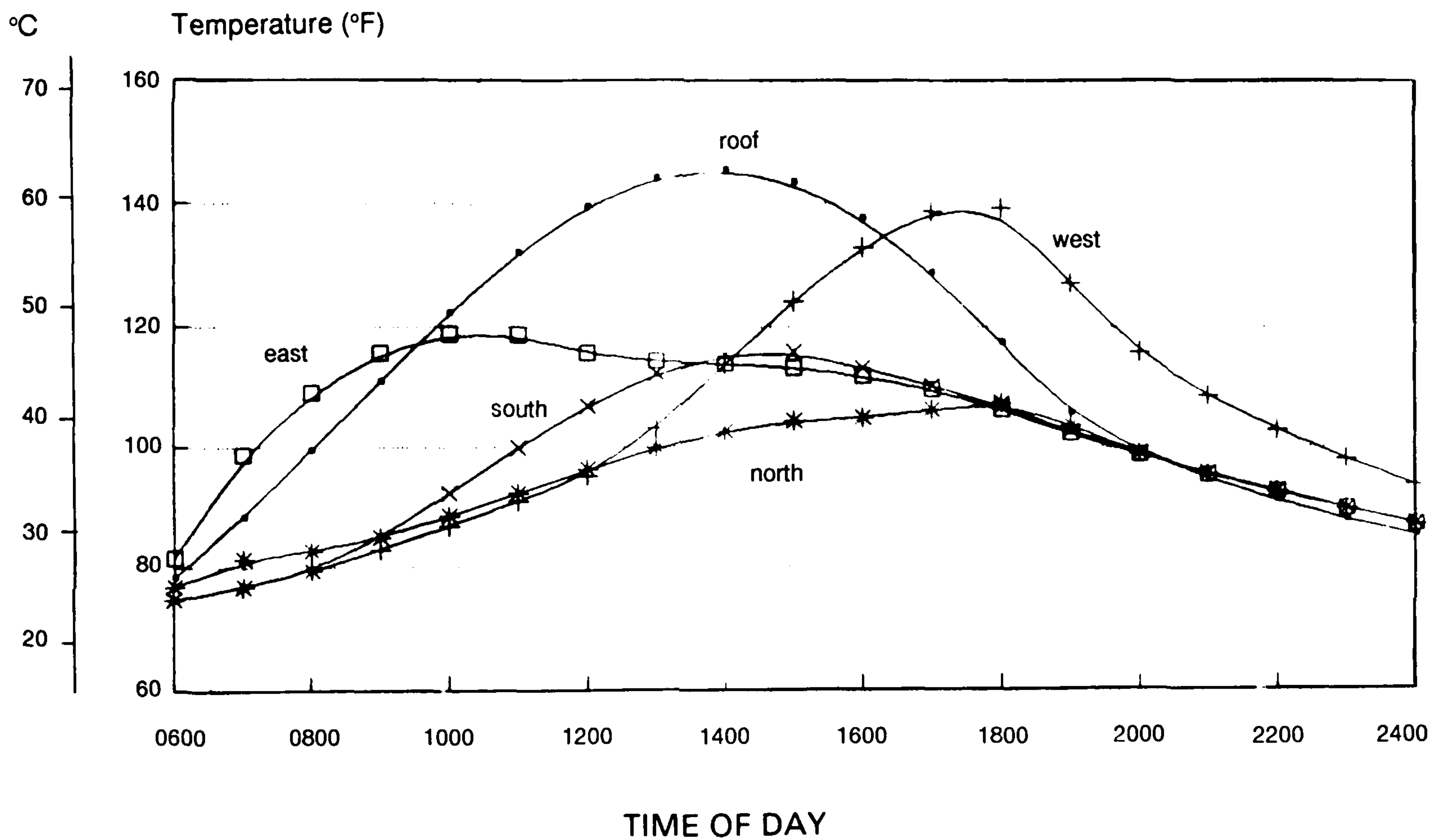
NOTES: (1) Washington, DC in July
(2) Wind velocity = 2 m/sec (4.5 mph)

Figure 14. Comparison of the "best" and "worst" west walls.



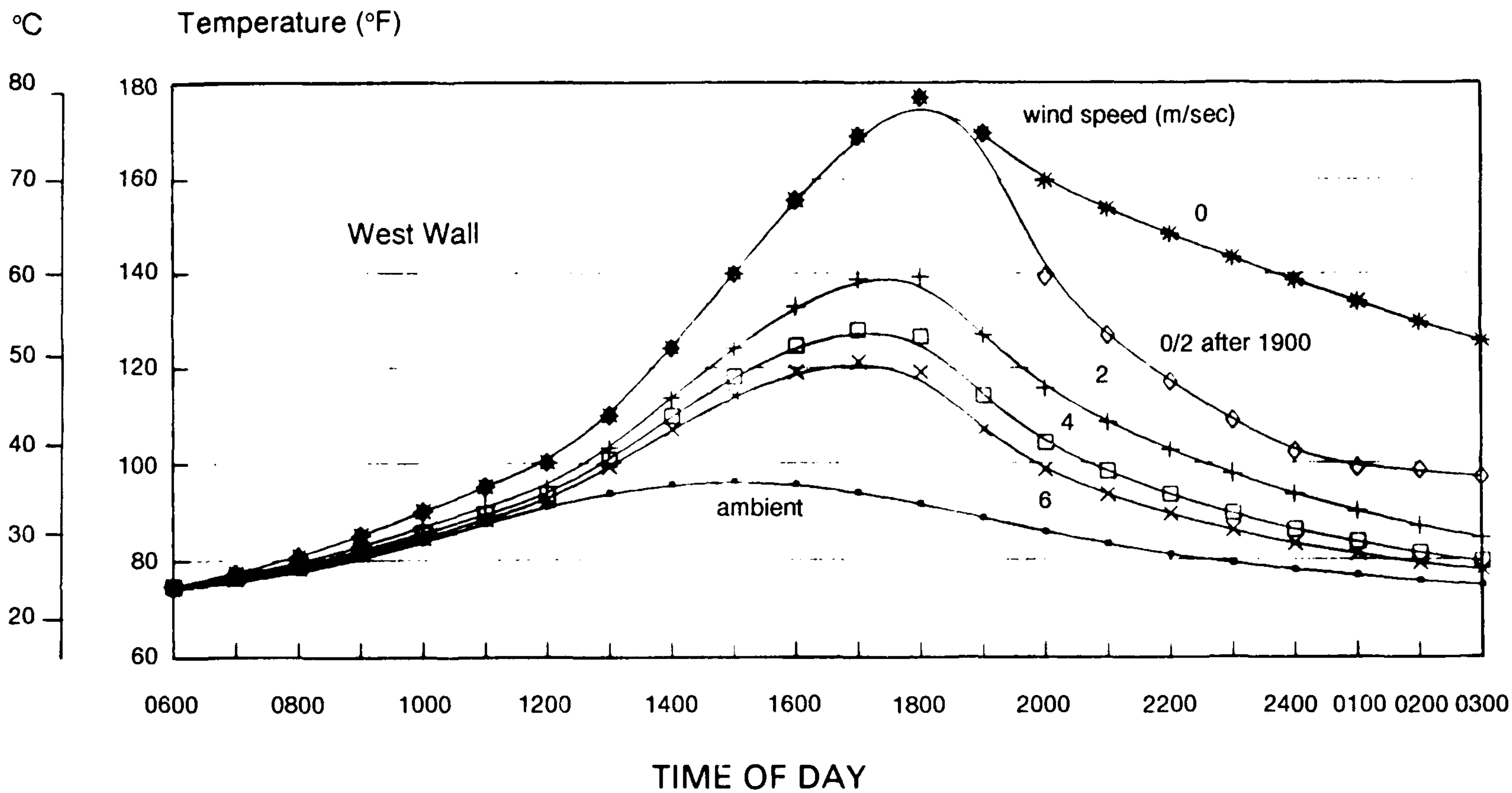
NOTES:
(1) Washington, DC in July
(2) Light wall construction
(3) Absorptivity = 0.3
(4) Overall wall resistance = 0.6 m^2-°C/kJ
(5) Roof construction not changed.

Figure 15. Wall and roof temperatures assuming the best construction type.



NOTES: (1) Washington, DC in July
(2) Heavy wall construction
(3) Absorptivity = 0.9
(4) Overall wall resistance = 1.0 m²-°C/kJ
(5) Roof construction not changed.

Figure 16. Wall and roof temperatures assuming worst construction type.



NOTES: (1) Heavy wall construction
(2) Absorptivity = 0.9
(3) Overall wall resistance = 1.0 m^2 - °C/kJ

Figure 17. Effect of wind velocity on the west wall temperature of a Washington, DC building in July.

Figures 18* through 21 show the variation in the temperatures of all four walls over a 12-hour period. The time of the year is used as a parameter, winter and then summer. A Washington, DC environment is assumed. As would be expected, the energy convected to the air during a summer day is somewhat greater. (Observe that the temperature differences are greater.) The solar radiation incident on the walls is greater. What would possibly not be expected is the significant convection to the air that still exists during the winter months. Notice also that, for this environment, the west wall is the hot wall during the summer; the south wall is the hot wall during the winter. (The effect of clouds and the shading provided by trees and nearby buildings would be similar.)

Calculated Values of Wall Heat Convection

Equations (1) were solved for a single building and also for the entire portion of Wisconsin Avenue adjacent to the Naval Observatory. The dimensions of the buildings and their locations are tabularized in Appendix C. In order to prevent the analyses from becoming overwhelming, Wisconsin Avenue was divided into eight regions. The HVAC loads and the wall convection off buildings located in each region were added together, and spread evenly along that portion of Wisconsin Avenue falling within each region. The concept is shown schematically on Figure 22. Observe that most of the current development is to the southwest of the Observatory.

Results for a late afternoon in July are summarized on Table 5. Q(cool) is the HVAC load. Q(roof) and Q(sides) are the energy being convected off the roof and four sides of the building(s). Locations correspond to the locations defined on Figure 22.

Discussion of Building Heat Transfer

Two further observations need to be emphasized. First, convection appears to be the major source of heat rejected off buildings during most of the day and, at least, into the early evening. Table 5 compares HVAC and convection during the late afternoon. For the single building, convection is about seven times greater than the energy discharged with the air conditioning. For the block sections of Wisconsin Avenue, the difference is less, but many of these buildings are small one- and two-story structures.

The second observation is that convection (and HVAC) off building walls occurs into the night. For buildings with walls of heavy construction, convection may still be significant at midnight or later.

---

*Figure 18 is analogous to Figure 9 with the absorptivity increased from 0.7 to 0.9.

NOTES: (1) Wind velocity = 2 m/sec (4.5 mph)
(2) Absorptivity = 0.9
(3) Overall wall resistance = 0.6 m²- °C/kJ

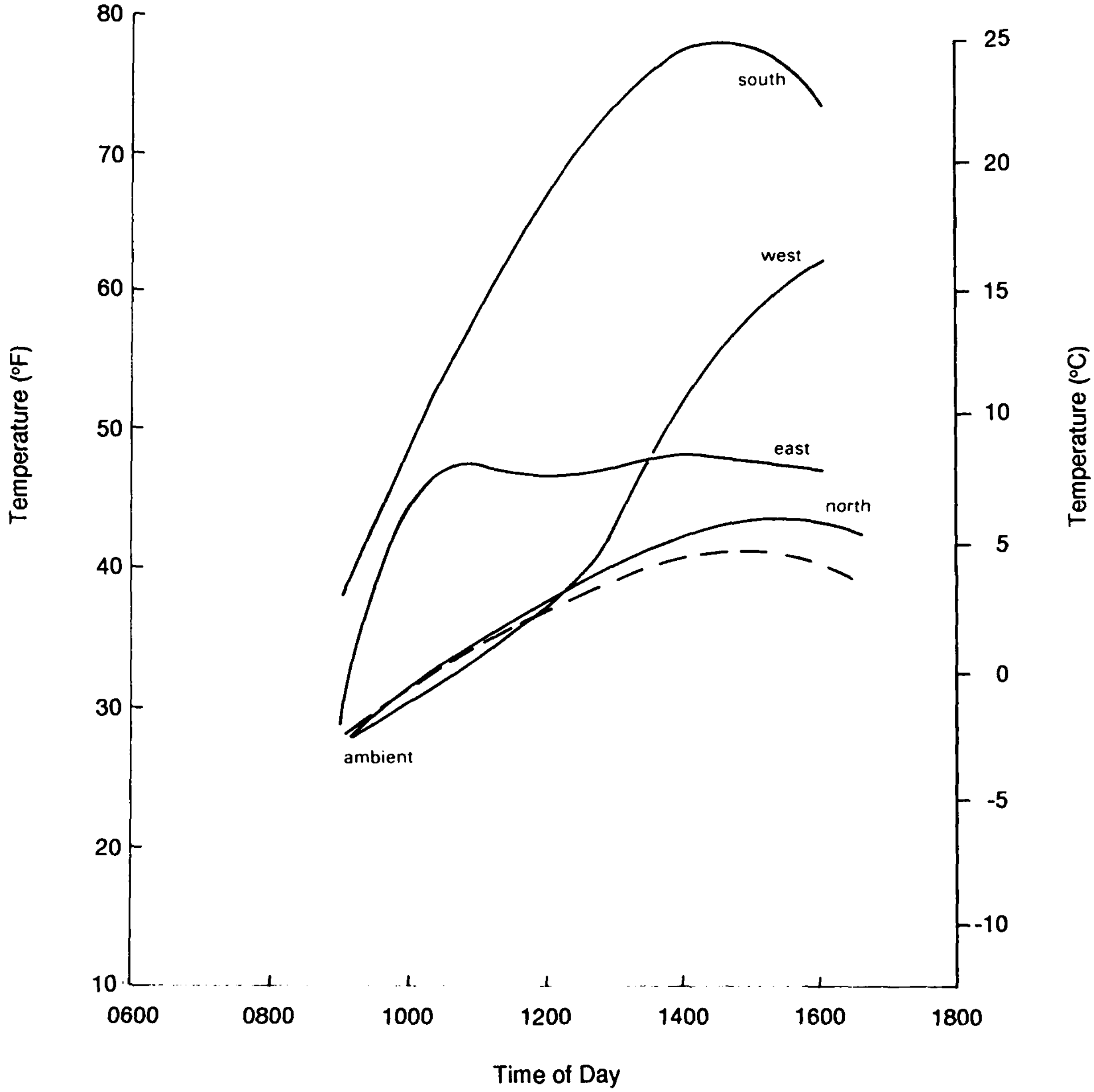


Figure 18. Building wall temperatures in Washington, DC during a calm day in winter.

NOTES: (1) *Wind velocity = 2 m/sec (4.5 mph)*
(2) Absorptivity = 0.9
(3) Overall wall resistance = 0.6 m^2 - °C/kJ

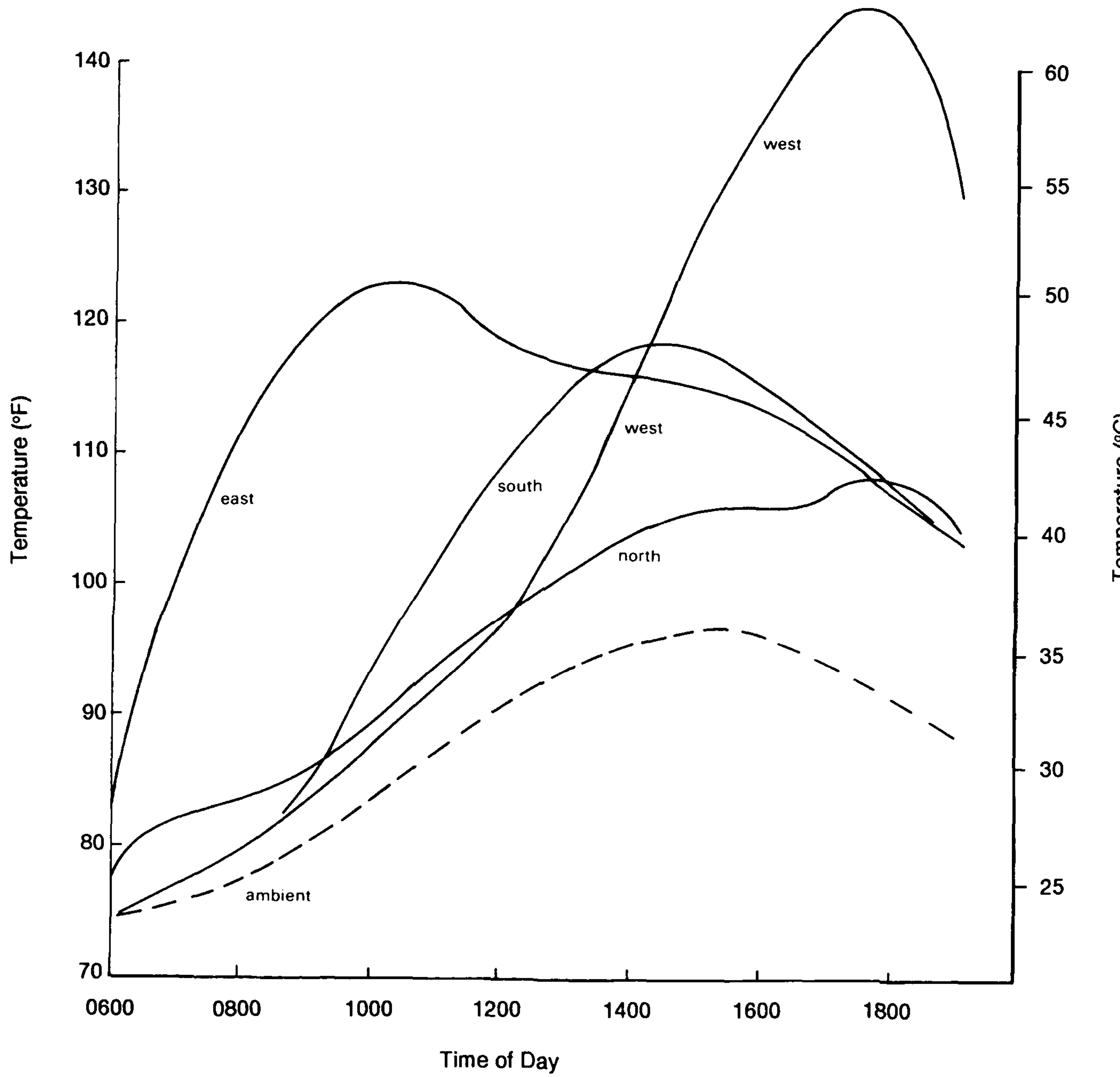


Figure 19. Building wall temperatures in Washington, DC during a calm day in July.

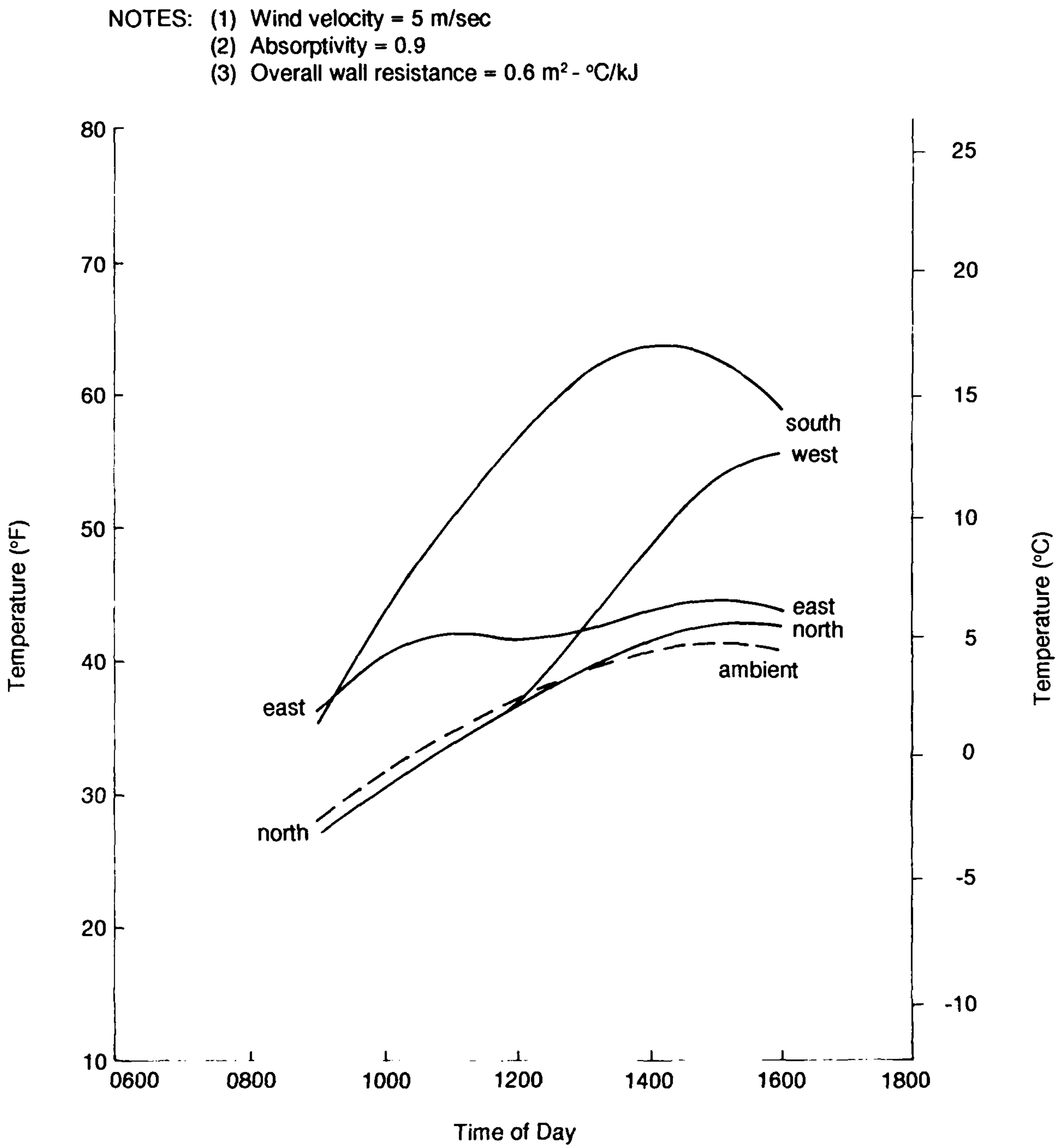


Figure 20. Building wall temperatures in Washington, DC during a windy day in January.

NOTES: (1) Wind velocity = 5 m/sec
(2) Absorptivity = 0.9
(3) Overall wall resistance = 0.6 m^2 - °C/kJ

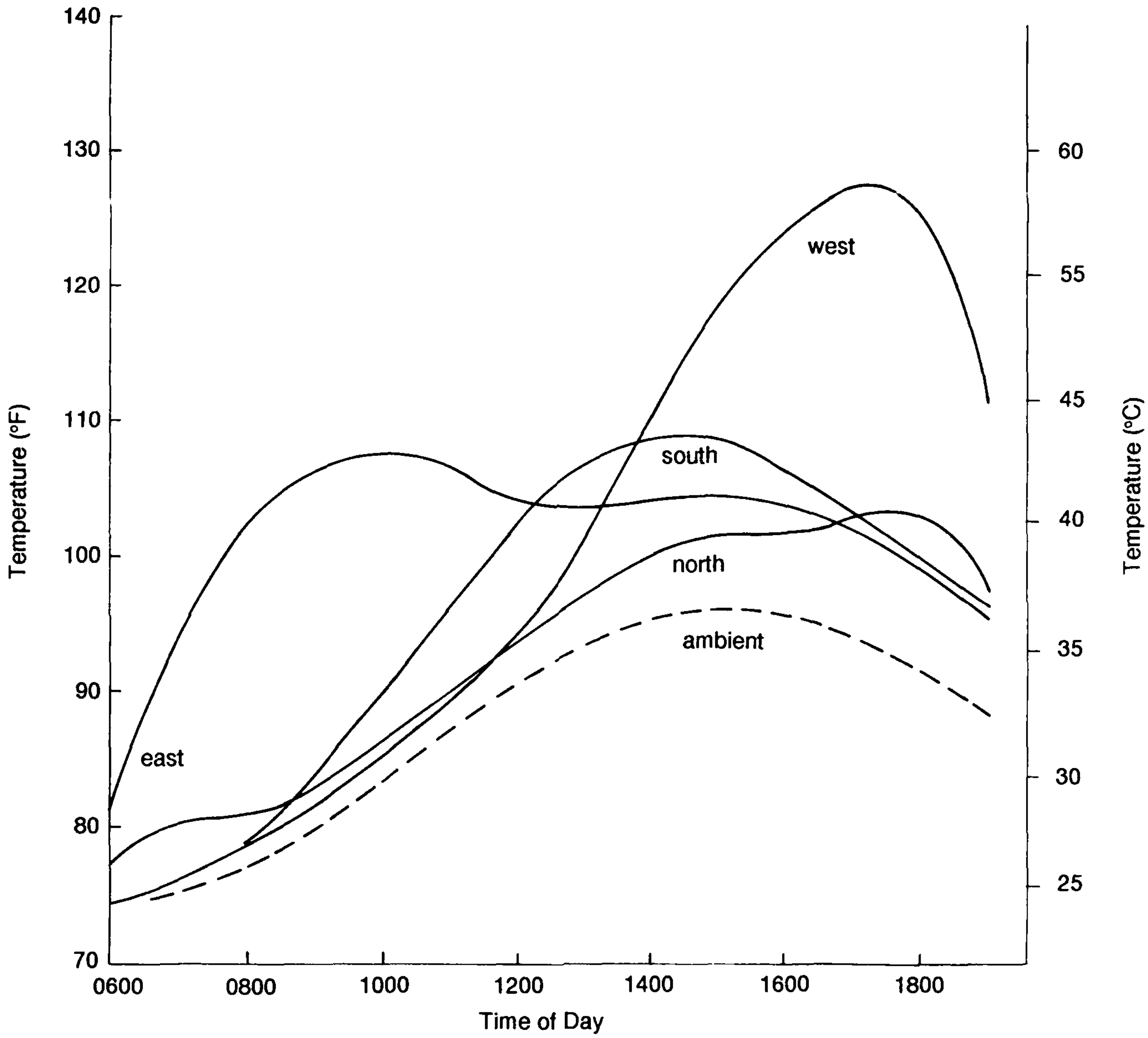


Figure 21. Building wall temperatures in Washington, DC during a windy day in July.

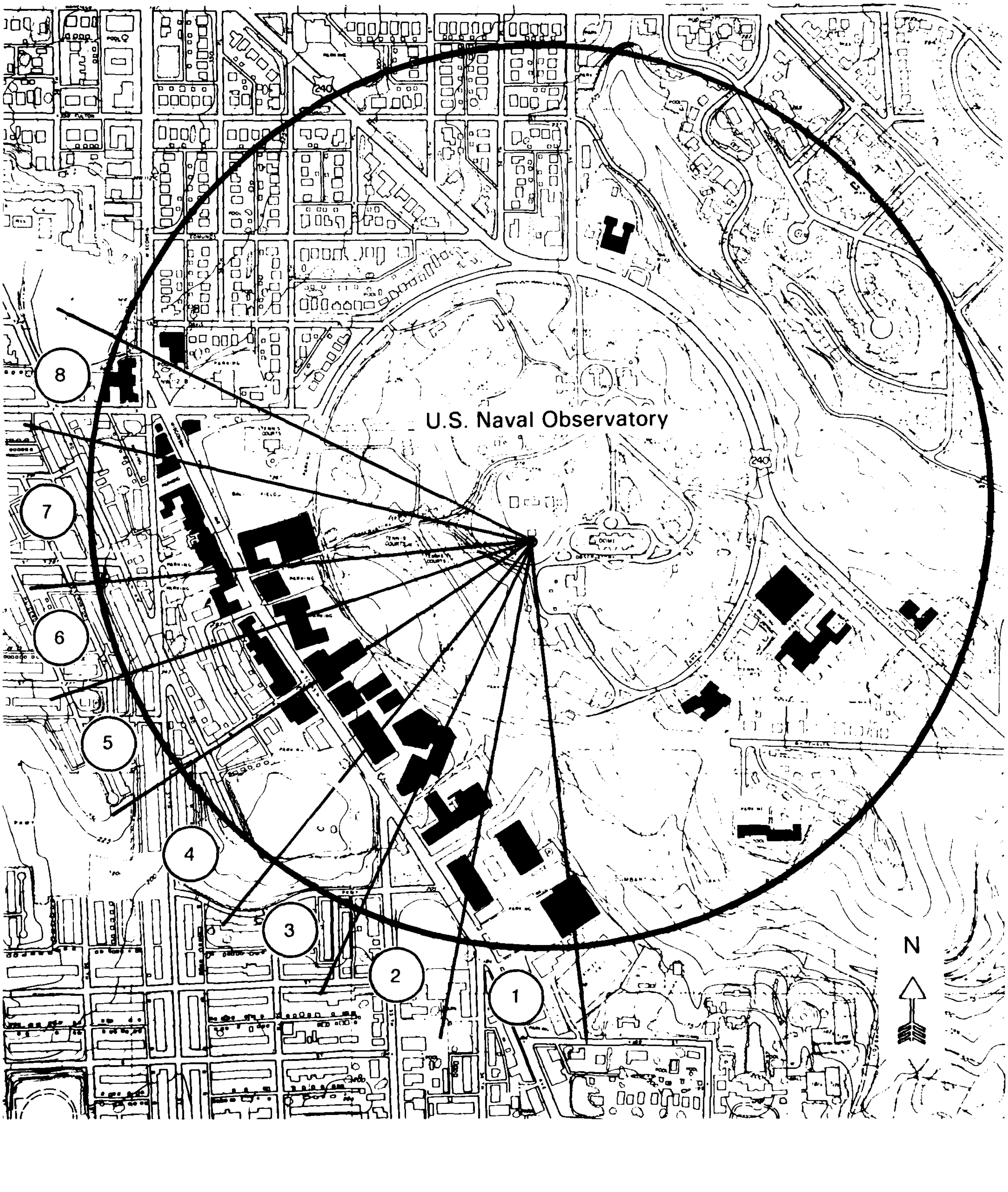


Figure 22. Schematic of the Naval Observatory showing the division of Wisconsin Avenue for the purpose of lumping building loads.

Table 5. Summary of Calculated Heat Rejection Off the Buildings Along Wisconsin Avenue in the Vicinity of the Naval Observatory During a Late Afternoon in July

Location	Q (roof) (Btu/hr)	Q (sides) (Btu/hr)	Q (cool) (Btu/hr)	Q (total) (Btu/hr)	Q (total) (watts)
1	2.65E7	9.95E6	1.33E7	4.98E7	1.46E7
2	1.83E7	1.65E7	1.47E7	4.95E7	1.45E7
3	1.21E7	1.07E7	9.73E6	3.25E7	9.52E6
4	2.60E7	1.13E7	1.22E7	4.95E7	1.45E7
5	1.38E7	7.16E6	9.88E6	3.08E7	9.02E6
6	1.09E7	5.90E6	5.09E6	2.19E7	6.42E6
7	1.50E7	4.93E6	7.48E6	2.74E7	8.03E6
8	1.19E7	1.34E7	7.44E6	3.27E7	9.58E6
Typical Single Building	6.54E6	7.50E6	2.10E6	1.61E7	4.73E6

Accuracy of the Building Load Calculations

Several assumptions were made in order to solve Equations (1):

1. No shading from adjacent buildings or from trees was considered. Shading provided by the building itself was considered.

2. Wind approaches the buildings undisturbed, with constant velocity, constant direction, and constant temperature.

3. The film coefficient is a function only of the undisturbed wind velocity. It is the same for all sides and the roof.

4. The shape of the buildings was not considered. For purposes of wall surface area calculations, all buildings were assumed to be square.

5. Heat conduction along the walls is negligible.

The error introduced with the assumptions was not numerically assessed. For the Wisconsin Avenue configuration, the assumption of no shading is good. Most of the taller buildings are not located next to each other. Furthermore, during the summer, the west wall is the hottest wall, and it is located along the street where there is no shading. The roofs are not shaded regardless.

As discussed previously, the prevailing winds in Washington, DC are from the west. Buildings to the west of Wisconsin Avenue are primarily single family homes and small shops. It is reasonable to assume that these structures would provide little resistance to the approaching wind. The assumption of an undisturbed wind is, therefore, probably good.

The next two assumptions are conservative. The upwind wall, a stagnation wall, would have a higher film coefficient than calculated (based on the wind blowing over a vertical wall). The downwind wall would have a lower film coefficient. During the summer, the upwind wall is the hot west wall.

A square building would have a smaller total wall surface area than a building with the same floor area but with any other shape. The calculated total convection heat transfer to the atmosphere will be smaller.

Finally, if conduction through the walls induced by significant temperature gradients is small, as shown on Figure 13, conduction along the walls, with very small temperature differences, is negligible.

AIR DENSITIES

Wind blowing over the buildings is heated by the HVAC discharge and by the energy convected off the warm walls of the buildings. This causes a local change in the properties of the air. These "pockets" of perturbed air are carried along with the wind, rising due to the buoyancy of the now warmer air. The buoyancy plus the turbulence of the air causes mixing, which further perturbs the downwind structure of the atmosphere.

The problem here is to determine that structure. The behavior of the atmosphere can be simulated mathematically with a continuum representation of conservation of mass (continuity), momentum, and energy, along with some appropriate relationship of state.

Equation of Continuity

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \qquad (4a)$$

Conservation of Momentum (Navier-Stokes Equations)

$$\rho\left[\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right] = X - \frac{\partial P}{\partial x} + \frac{\partial}{\partial x}\left[\mu\left(2\frac{\partial u}{\partial x} - \frac{2}{3}\,\mathrm{div}\,\vec{W}\right)\right] \qquad \ldots (4b)$$

$$+ \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right]$$

$$+ \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)\right]$$

with similar expressions for the y and z components.

Conservation of Energy

$$\rho\, g\, C_p \left[\frac{\partial T}{\partial t} + u\,\frac{\partial T}{\partial x} + v\,\frac{\partial T}{\partial y} + w\,\frac{\partial T}{\partial z}\right] = \frac{DP}{Dt} + \frac{\partial}{\partial x}\left(k\,\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\,\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\,\frac{\partial T}{\partial z}\right) + \mu\,\Phi \quad \ldots (4c)$$

where: u,v,w = velocity components in x, y, z directions, respectively,

ρ = density

g = acceleration of gravity

P = pressure

μ = viscosity

X = body forces

k = thermal conductivity

C_p = specific heat

t = time

T = temperature

and

$\vec{W}$ = velocity vector $\equiv u\,\vec{i} + v\,\vec{j} + w\,\vec{k}$

Φ = dissipation function

$$\Phi = 2\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right] + \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2 - \frac{2}{3}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)^2$$

five equations and the six unknowns: the air velocity components u, v, w and the thermodynamic properties of the atmosphere, P, ρ, T. The final relationship is an equation of state,

$$f\,(P,\rho,T) = 0 \qquad (5)$$

Turbulence further complicates Equations (4). The transport properties are now dependent upon the flow field. This dependency is extremely complex and has, to date, defied a theoretical description. The

usual approach is semi-empirical, assuming some form for the relationships between fluid properties and flow field and experimentally fitting constants in these relationships (Ref 4 and 5).

The forces acting on the flow field due to the buoyancy of the warm pockets of air must also be included in the mathematical representation of the problem.

Boundary conditions (BC) are relatively straightforward. The upwind BCs are variables to be examined, wind velocity, temperature, and wind direction. The mass and energy input from the buildings have been discussed in detail. The geometry is set, i.e., the Naval Observatory and surroundings. The only BC decisions to be made prior to attacking Equations (4) and (5) are to define the type and extent of the boundaries. For example, how much of the atmosphere must be considered? How detailed must the buildings and the ground be? These boundary conditions were established by trial and error. They will be discussed further.

Equations (4) and (5) can be simplified somewhat by making several good additional assumptions. The air is considered incompressible. With wind velocities of a few meters per second, density of the air will vary only with temperature. The air is assumed to act as an ideal gas. Finally, the analyses are considered independent of time. For the minute or two that it takes the air to pass between buildings, the temperature of the walls will remain nearly constant.

PHOENICS PROGRAM

Even with these assumptions, Equations (4) are too complex to solve in closed form. They were solved numerically, employing the PHOENICS code. PHOENICS is a general purpose heat transfer/fluid flow computer program developed by CHAM, Ltd. of London (Ref 6). It is an iterative code, solving finite volume approximations of Equations (4).

Turbulence is simulated in PHOENICS by using an effective exchange coefficient consisting of both a molecular and turbulent component. For example, the viscosity would be approximated as:

$$\mu \leftarrow \mu_{eff} = \mu + \mu_{turb}$$

where: μ = molecular (laminar) viscosity

μ_{turb} = viscosity to account for turbulence

Various empirical relationships have been used to calculate the effective exchange coefficients. PHOENICS employs the κ-ε model,

$$\mu_{turb} \propto \rho \frac{\kappa^2}{\varepsilon}$$

The parameters κ (turbulence kinetic energy) and ε (dissipation rate) then become additional unknowns to be solved for (Ref 6):

$$\kappa = \frac{1}{2}\left(u'^2 + v'^2 + w'^2\right)$$

$$\varepsilon = \kappa^{1.5}/\ell_m$$

where: u', v', w' = velocity fluctuations

ℓ_m = appropriate mixing length

Buoyancy of the hot air is included in PHOENICS by adding a buoyant force to the equation for conservation of momentum in the vertical direction (Ref 7)

$$X = -g \rho \beta (T_\infty - T_{ref})$$

where: g = acceleration of gravity

β = coefficient of expansion

T_∞ = ambient (air) temperature

T_{ref} = some reference temperature

Once the boundary conditions are set, PHOENICS requires that the domain of the problem be divided up into a series of "finite volumes" as illustrated on Figure 23. Properties such as temperature and density remain constant across each volume. Finite volume approximations of Equations (4) are then solved for each volume, i.e., a series of simultaneous equations, with boundary conditions for each volume set by values at the adjacent volumes.

If these finite volumes are infinitesimally small and the domain of the problem is infinitely large, then the PHOENICS solution to Equations (4) is exact. Such an approach is both numerically and economically impossible. Compromises have to be made. The best approach is to start with a coarse grid/small domain simulation that is simple and cheap, then gradually decrease the grid size and increase the domain until the change in the results is less than the desired accuracy.

Time limitations prevented this. The fine 8 x 8 x 8 m^3 grid shown in Figure 23 was increased to 25 x 25 x 25 m^3 to assess the grid size. There was no noticeable change in the range of the calculated properties of the atmosphere. Locations of the isopycnics (lines of constant density) shifted by perhaps 10 meters (30 feet) in the region directly over the Observatory.

Based on trial and error, the atmosphere remained undisturbed 300 meters above and 200 meters to the sides of the buildings. Also based on trial and error, it was found that the actual shape of the buildings had a negligible effect on the downwind structure once beyond 100 meters. Buildings were assumed to be rectangular in shape. Trees and the slope of the ground were found to have little effect on this problem.

RESULTS

The objective of this work is to determine the downwind perturbations of the atmosphere. Results are presented in the form of isopycnics, lines of constant density, predicted in the atmosphere above

the Naval Observatory. Figure 24 shows the effects of the single building described in Appendix C. An east-west plane is shown. It is July at about 5 pm. A 2 m/sec wind is blowing directly from the west, from left to right on this figure. The air arrives at a temperature of 32.8 °C (which corresponds to a density of 1.151 kg/m^3), is heated by the building, and proceeds on to the transit house. The bottom part of the figure is identical to the top with additional isopycnics.

For an ideal gas, the density is inversely proportional to the temperature. Pockets of low density correspond to pockets of warm air. The center of the "plume" on Figure 24 is the warmest. It is rising, spreading, and cooling as it is blown from the building to the transit house.

Figure 25 plots isopycnics induced at 10 pm by the same building on the same day and in the same wind.

The effects of the entire portion of Wisconsin Avenue to the west of the Observatory are shown on Figure 26. This is Wisconsin Avenue as it is today. The difference between 26(a) and 26(b) is the direction of the wind. On Figure 26(a), the wind is blowing through the relatively heavily developed southwest portion of the avenue. On Figure 26(b), the same wind is blowing through the lightly developed northwest section of Wisconsin Avenue.

Figure 27 is identical to Figure 26 with the "typical single building" replacing all the smaller buildings. See Table C-1.

DISCUSSION

The only difference between Figures 24 and 25 is the time. Both show the structure of the atmosphere downwind from the same single building. The wall has cooled off somewhat between 5 pm and 10 pm. As a result, convection is less; heat transferred to the air has decreased from 4.73 million watts down to 2.65 million watts. Air over the Observatory at 5 pm is more perturbed. Density gradients are larger. The buoyancy of the warm pockets of air is greater. Therefore, the plume is rising a little faster. Similar characteristics could be shown for the other parameters examined.

The difference between Figure 26 and Figure 27 is the size of the buildings. Replacing small buildings with large buildings, a condition assumed to generate Figure 27, will increase both the HVAC loads and the convection surface area. A more distorted atmosphere can thus be expected. The difference shows up better when comparing Figures 26(b) and 27(b); more small buildings are being replaced in the path of the wind.

The problem of heat induced atmospheric perturbations is very much a three-dimensional problem. Even for a single building, there is mass flow in all directions. On Figures 24 and 25, the warm air is rising as it is swept eastward by the wind. As it rises, it is replaced with cooler air flowing in from the sides, i.e., from the north and south.

If there are several buildings; for example, the entire section of Wisconsin Avenue passing west of the Observatory; the three-dimensional flows become very complicated. Different buildings are heating the air at different rates. Buoyancy forces are different, and different pockets of air are rising at different rates. Instead of relatively symmetric plumes such as shown on Figures 24 and 25, isopycnics become very complex, impossible to intuitively predict, compare Figures 24 and 25 with Figures 26 and 27.

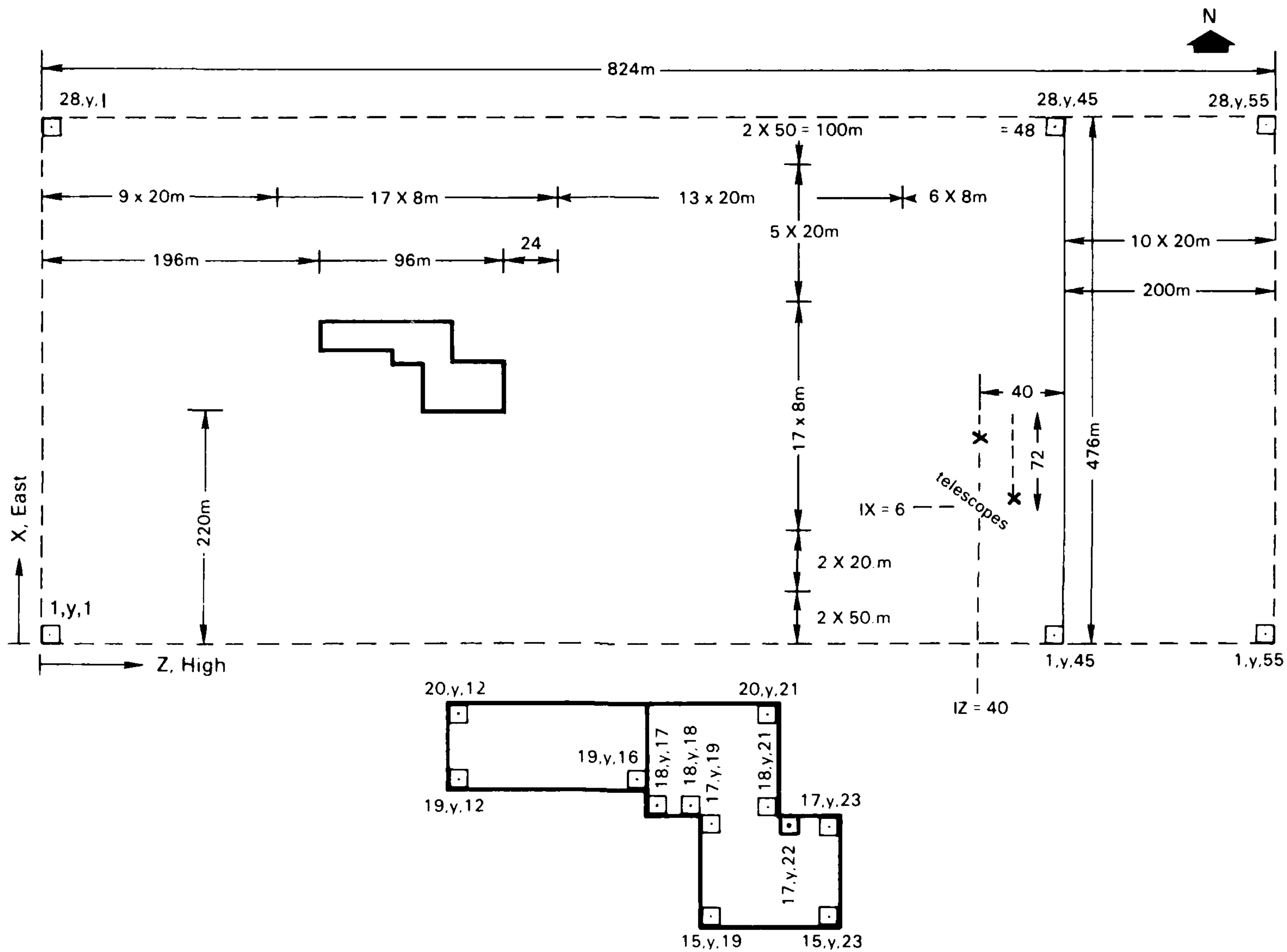


Figure 23a. Finite volume grid of atmosphere above the Naval Observatory defined for PHOENICS - top view.

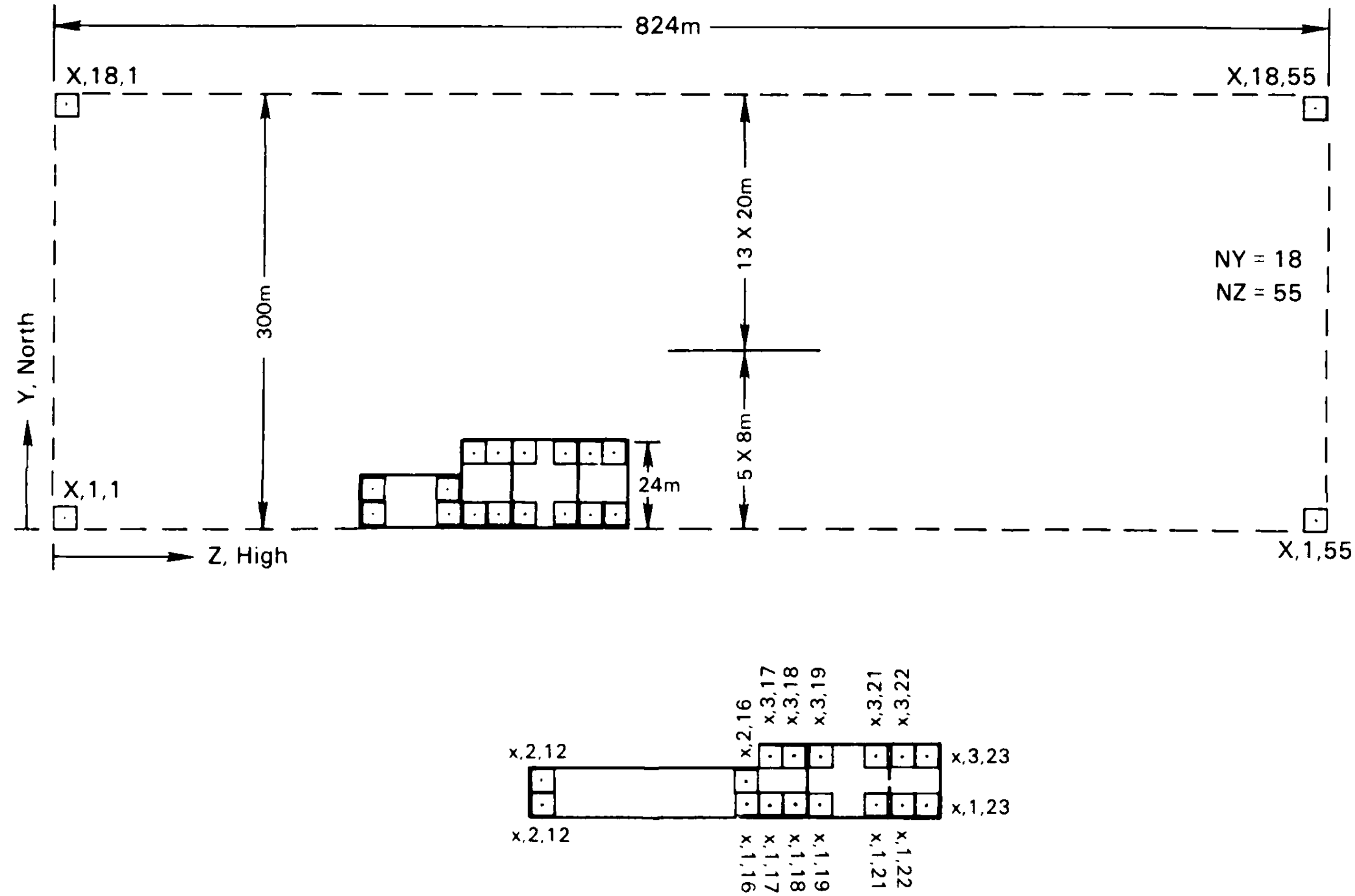


Figure 23b. Finite volume grid of atmosphere above the Naval Observatory defined for PHOENICS - side view.

NOTES: (1) E-W plane for a late afternoon in July
(2) Wind a 2 m/sec, blowing from the west
(3) Total heat flux out of the building = 4.73 $(10)^6$ watts

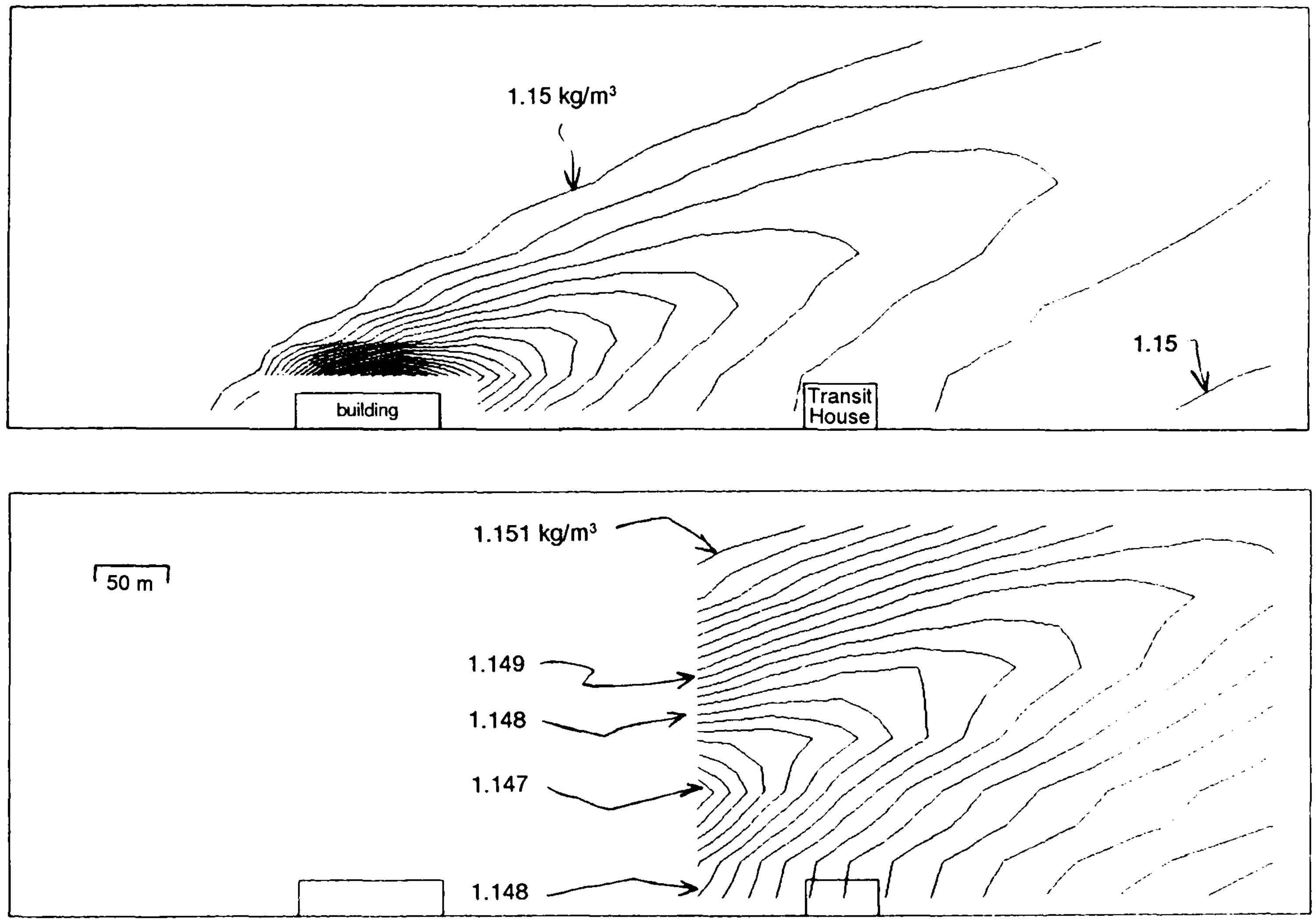


Figure 24. Predicted isopycnics (kg/m³) in the vicinity of the Naval Observatory induced by typical single building.

NOTES: (1) E-W plane for a July evening at 10:00 pm
(2) Wind a 2 m/sec, 27.2°C , blow from the west
(3) Total heat flux out of the building = 2.65 $(10)^6$ watts

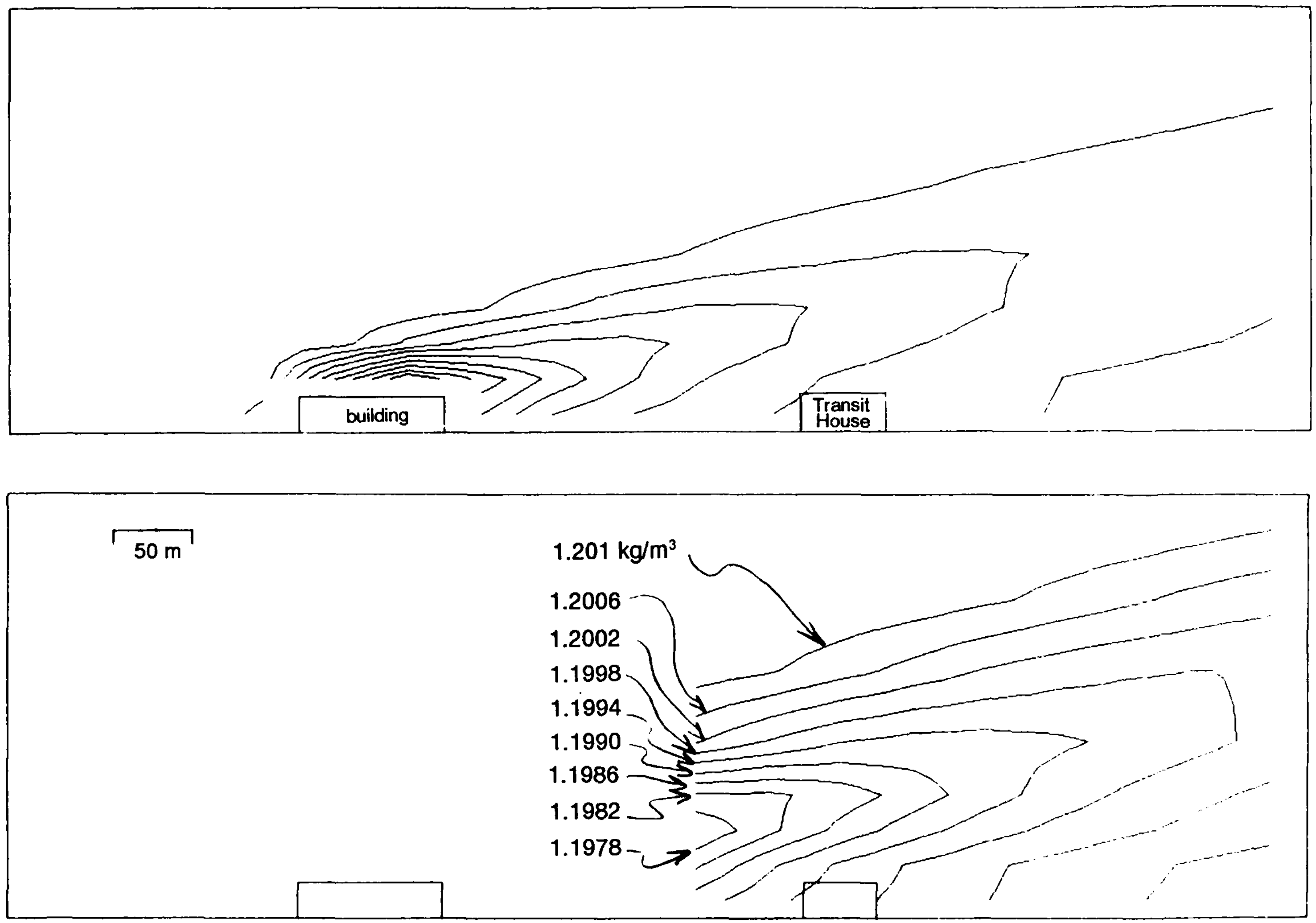
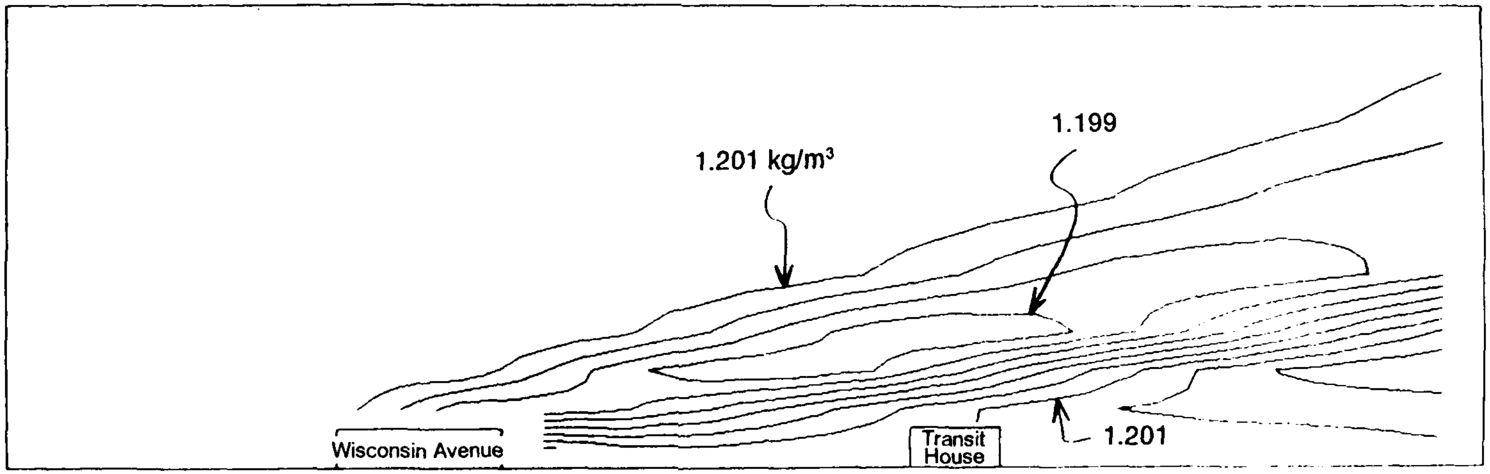


Figure 25. Predicted isopycnics (kg/m³) in the vicinity of the Naval Observatory induced by single building at 10:00 pm.

NOTES: (1) July evening at 10:00 pm
(2) Wind at 2 m/sec, 27.2°C

(a) SW-NE plane, wind blowing from the SW



(b) WNW-ESE plane, wind blowing from the WNW

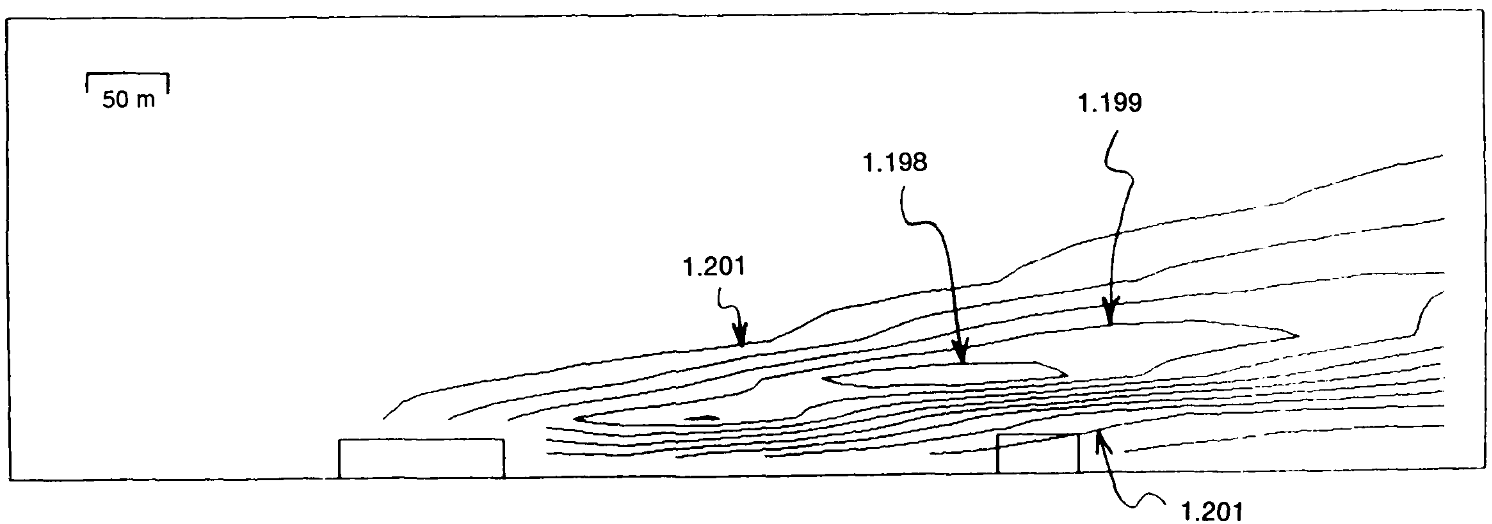


Figure 26. Predicted isopycnics (kg/m³) in the vicinity of the Naval Observatory with current Wisconsin Avenue buildings.

NOTES: (1) July evening at 10.00 pm
(2) Wind at 2 m/sec, 27.2°C

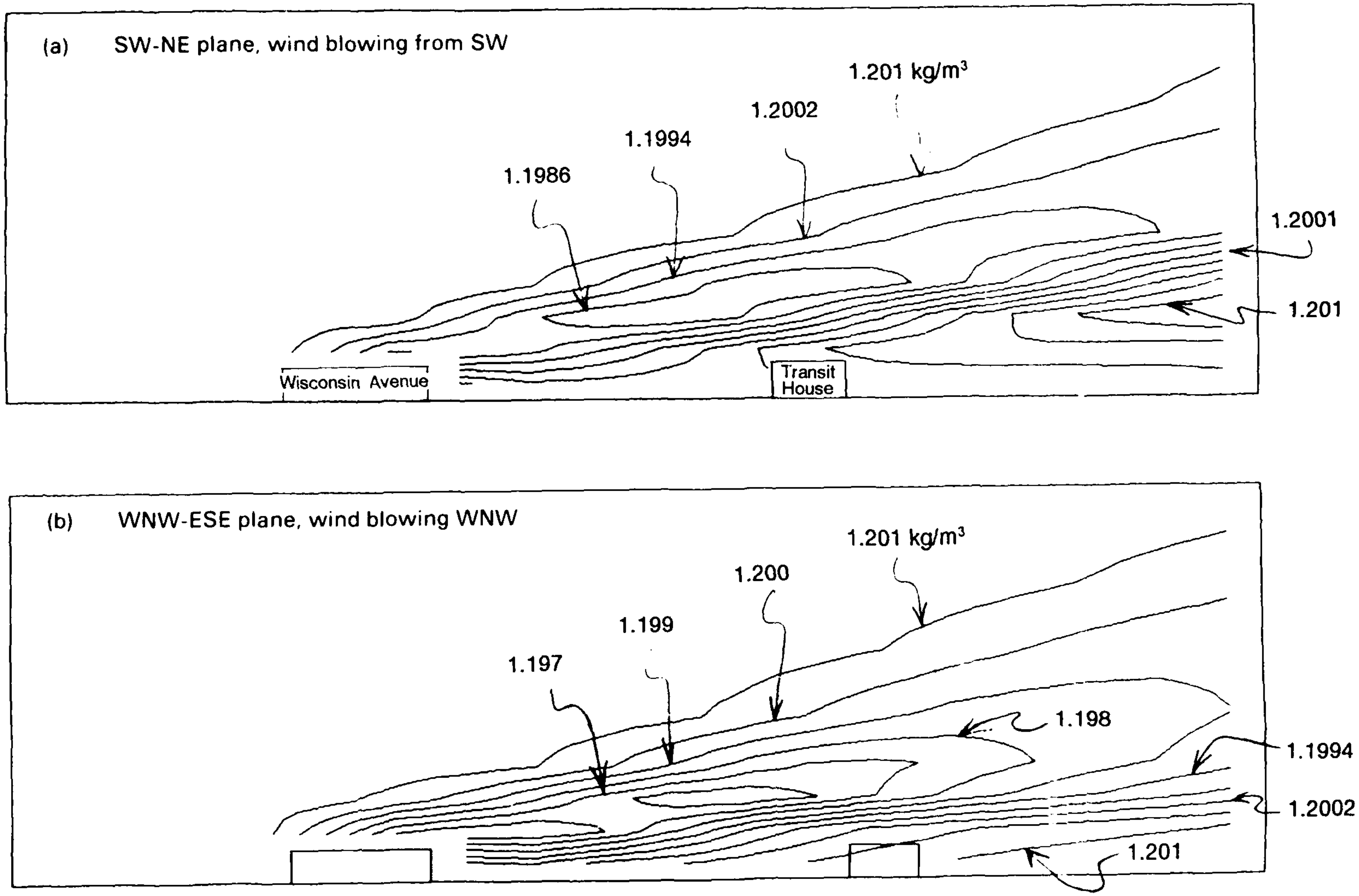


Figure 27. Predicted isopycnics (kg/m³) in the vicinity of the Naval Observatory induced by buildings along Wisconsin Avenue; includes future development with existing zoning.

The three dimensionality of the problem is better illustrated on Figure 28. This figure shows air flows in the north-south plane through the transit house. This plane is perpendicular to the undisturbed direction of the wind. Eddies with diameters of up to 200 meters are being formed, with wind velocities of 1 m/sec or greater (compared with an undisturbed wind velocity of 2 m/sec). The structure of the atmosphere in this plane is shown on Figure 29.

OBSERVATIONAL ERROR

Determination of the observational error induced by building heat generated density perturbations in the atmosphere was not a part of this work. It was the catalyst for the effort, however, and a short discussion is appropriate.

The amount of the anomalous refraction depends upon the average angle of tilt of the isopycnics, the thickness of the region within which the tilts occur, and the change of the density within this region. A good approximation is given by the simplified formula:

Anomalous Refraction = Constant x Average Tilt Angle x Thickness

For the single building and under the conditions assumed to produce Figure 24, this formula predicts an anomalous refraction of about 0.1 seconds of arc when looking straight up from the Transit House. If all of Wisconsin Avenue is included, assuming future development, an anomalous error of 0.3 seconds of arc is predicted.

This seems like a very small error until one considers that the formal error of a star position determined at the Naval Observatory is about 0.04 seconds of arc. Some defense systems currently in use require accuracies in the range of 0.1 to 0.5 seconds of arc.

This type of observational error is discussed in more detail in Appendix A and in References 8 and 9.

REFERENCES

1. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Handbook: Applications, Atlanta, GA, 1982.

2. __________. Handbook: Fundamentals, Atlanta, GA, 1985.

3. Elite Software Development, Inc. User's Guide: Commercial HVAC loads, Version 2.3, Bryan, TX, 1984.

4. J.O. Hinze. Turbulence, second edition, New York, NY, McGraw-Hill, 1975 (Chapter 5).

5. Princeton University. Technical Report No. 914: A study of turbulent boundary layer models, parts I and II, by G.L. Mellor and H.J. Herring. Princeton, NJ, May 1970.

6. CHAM Limited. Technical Report TR/200: The PHOENICS reference manual, by H.I. Rosten and D.B. Spalding. London, England, Oct 1987.

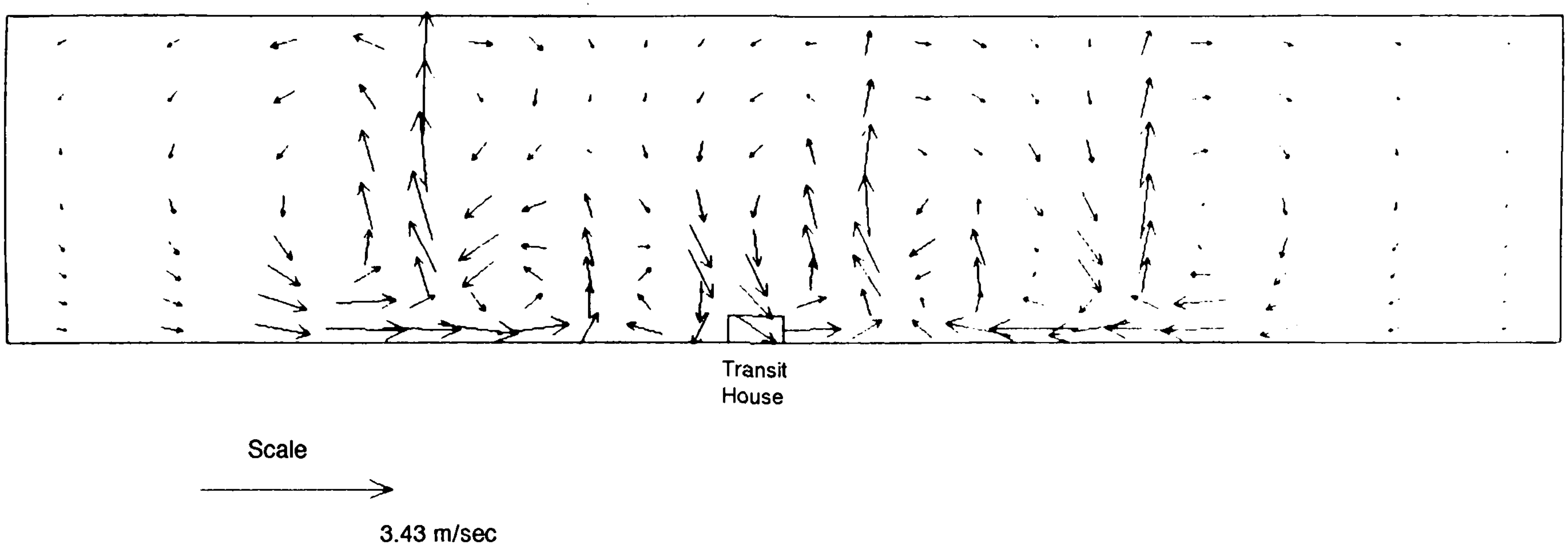
7. H. Schlichting. Boundary layer theory, 4th ed., New York, NY, McGraw-Hill, 1960 (p 295).

8. J.A. Hughes. "Environmental systematics and astronomical refraction II," in Refractional Influences in Astronomy and Geodesy, ed. by E. Tengstrom and G. Teleki. International Astronomical Union, Upsala, Sweden, 1979, pp 13-25.

9. J.A. Hughes and C.A. Kodres, "Pollution effects from large buildings," in proceedings of International Astronomical Union Colloquium No. 112: Light Pollution, Radio Interference, and Space Debris, Washington, DC, Aug 1988.

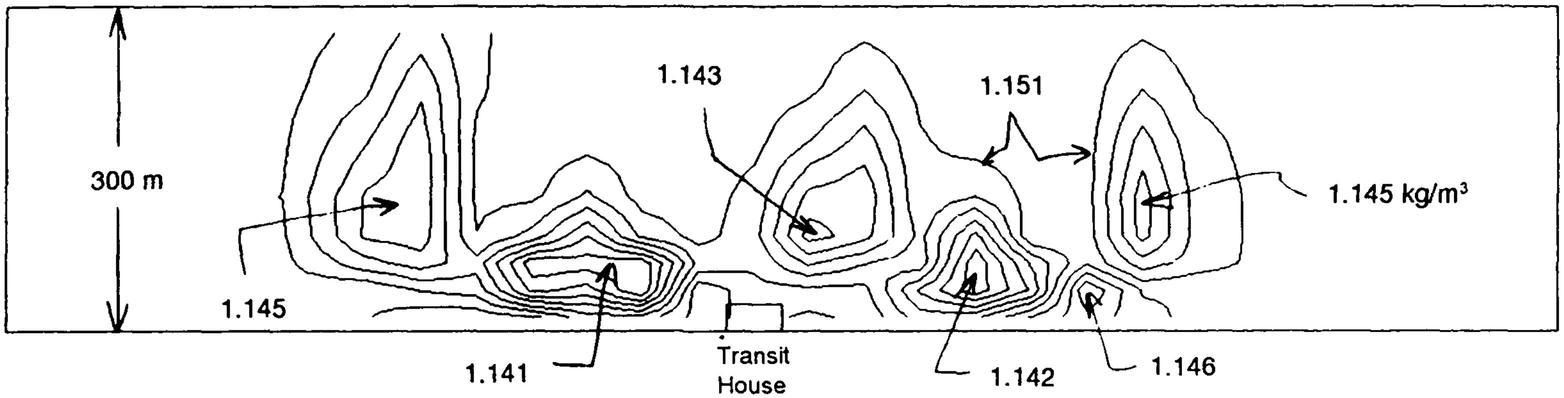
10. R. Siegel and J.R. Howell. Thermal radiation heat transfer, 1st ed., New York, NY, McGraw-Hill, 1972 (Appendix D).

11. Insolation Data Manual, Long-Term Monthly Averages of Solar Radiation, Temperature, Degree-Days, and Global K_t (bar) for 248 National Weather Service Stations. Solar Energy Information Data Bank. Solar Energy Research Institute, Golden, CO.



NOTES: (1) NS plane for a late afternoon in July
(2) Undisturbed wind at 2 m/sec, from the west
(3) View of the Transit House from the west

Figure 28. Predicted wind vectors in the vicinity of the Naval Observatory when existing Wisconsin Avenue buildings are each replaced with the typical building.



NOTES:
(1) NS plane for a late afternoon in July
(2) Wind at 2 m/sec, 32.8 °C, from the west
(3) View of Transit House from the west
(4) Isopycnics at equal intervals

Figure 29. Predicted isopycnics (kg/m³) in the vicinity of the Naval Observatory when existing buildings are each replaced with the typical building.

Appendix A

Statement of
Dr. James A. Hughes
Director, Astrometry Department
U.S. Naval Observatory
on
Zoning Case No. 87-34
before the
District of Columbia Zoning Commission

25 February 1988

The Navy, the Department of Defense in general and certain space-based activities require sophisticated celestial reference systems for navigation and positioning. Such systems consist of highly accurate star positions and motions and provide coordinate grids which one uses to specify locations and directions. Such a grid is entirely similar to lines of latitude and longitude on the surface of the Earth, except in this case they are located on the sky. The word, "navigation," is used here in a general sense which certainly includes classical navigation, but which today is primarily concerned with much more advanced applications such as satellite navigation, missile guidance systems, stellar tracking systems, satellite station keeping and various geodetic applications such as determining azimuths for orienting terrestrial coordinate systems. The accuracies of star positions required by these various applications vary widely. Classical sextant navigation, for example, does not require extreme accuracy, but many modern applications exhaust the currently available accuracy. Naturally we are primarily concerned with the most demanding requirements. In addition, very extensive academic and scientific use is made of star positions and motions. In short, the same data which permit the specification of a high precision azimuth for military or geodetic purposes may also be utilized in a purely academic way to determine the distance to a galaxy. In both cases, the crucial item is the existence of a fixed, non-rotating celestial reference system. Such a system is often referred to as an inertial reference system.

The Astrometry Department of the U.S. Naval Observatory is charged with determining and maintaining such celestial reference systems. The U.S. Naval Observatory is the sole institution in the United States which does this kind of work. This is so for both historical and practical reasons. For example, the work requires long-term commitments of major resources which are often inappropriate for universities. A single observing program can last a decade, with a few additional years required for the complete mathematical and statistical discussion of the data. This task forms a major part of the mission of the Observatory,

and involves making observations with various specialized telescopes including Transit Circle Telescopes. It is the threat to the work of the Washington Transit Circle which brings us here as petitioners. These telescopes are small, but ultra precise, state of the art instruments used to directly measure large angles on the sky to exceedingly high accuracy. The observational data consists of angular zenith distances measured to the North and to the South, plus the time at which an object crosses the local meridian. Such observations have been made from Washington at the U.S. Naval Observatory for about one century and a data base, internationally acknowledged to be the world's best of its kind, has been painstakingly built up from a series of long term observing programs. This observing effort continues to the present time. The current observing program in Washington includes about 35,000 stars plus the Sun, Moon and major and minor planets. High quality astronomical observations of tens of thousands of stars continue to be made in Washington. Contrary to usual astronomical practice, observations are made around the clock, with daytime observations made of the brightest stars, the planets Mercury, Venus and Mars, and of course, the Sun. These observations are necessary to derive an inertial coordinate system. At the present time however, large commercial development around the Observatory, especially along Wisconsin Avenue, is jeopardizing these astronomical data gathering efforts.

Commercial development, as represented by large buildings, has two deleterious effects on the observing environment: (1) it contributes to the general ambient level of artificial lighting, and (2) it acts as a source of heat (in both the summer and winter), which causes various atmospheric effects which adversely affect astronomical observing. This heating is due to space heating in the winter and to air conditioning in the summer, and is also due to the heat "soaked up" by buildings during sunny days at any time of the year. All of these heat sources are generally proportional to the bulk of a building, although specific usage might produce relatively minor variations. Dr. Kodres of the Naval Civil Engineering Laboratory will discuss these effects as part of his presentation to you.

Light pollution is currently of lesser concern to us. We have dealt with that problem by relocating certain observing programs to our Flagstaff, Arizona facility. That station was specifically established for programs using larger telescopes and/or requiring a dark sky. The programs now being carried out in Washington are minimally affected by the generally high sky brightness in the area. The Naval Observatory has deployed its telescopes to suit the needs of the various observing programs.

Heat emitted from large buildings, however, remains a serious problem. Unlike the case with light pollution, we cannot simply relocate the transit circle telescope program without gravely compromising a vital data base compiled over many years. It is by comparing contemporary observations with observations made decades ago, that one determines how the stars are moving. These angular stellar motions are caused by the stars' velocities through space. These velocities consist of various components, for example, galactic rotation and star streaming plus the stars' own peculiar individual velocities. In any event, a knowledge of these motions is essential if one is to correctly update

the stellar reference system, or indeed to scientifically study the motions themselves. Combining new observations made from a new site of unknown characteristics would introduce systematic differences between old and new positions and result in spurious motions. It is precisely the homogeneity of the Washington observations which makes them the most valued of their type in the world. This homogeneity depends upon many factors. For example, the seasonal motions of the massive piers supporting the telescope and the exact reactions of the so-called "meridian marks" which are used to measure rates of change of the azimuth of the instrument are reliably known for the Washington installation at the level of 0.01 millimeter (0.0004 inch). This kind of prediction capability comes strictly from many years of study of the Washington site.

Heat energy injected into the atmosphere by a building causes various effects. These include turbulence and large scale changes in the structure of the atmosphere as represented by its temperature and its density. Dr. Kodres will discuss these effects in more detail. From the astronomical point of view, turbulence at great heights in the atmosphere (~10 km) can cause rapid variations in the brightness of a star's image in a telescope. This effect is referred to as "scintillation." This kind of variation is of minimal concern for the kind of observations being made at the Naval Observatory. In any event, it is unlikely that the nearby buildings are solely responsible for the observed scintillation. In addition, turbulence relatively nearby a telescope (say ~1 km or nearer) can cause an image to rapidly and randomly move about its average position and to vary in sharpness. This effect is called, by astronomers, "astronomical seeing." If we were engaged in making observations looking out over some of these large, nearby buildings, then we would no doubt be concerned with the deterioration in the astronomical seeing which they would cause. However, we do not observe over these buildings so their effects upon seeing are also not a concern. Recall that the transit circle telescope observes only to the North and to the South. Allow me to emphasize therefore, that neither of these turbulence-induced effects are of primary concern in the present matter. The Observatory is very concerned, however, with another, perhaps more subtle effect, namely, "anomalous refraction." This effect is caused by the changes in the atmospheric structure mentioned above.

To best understand anomalous refraction it is helpful to consider what the situation would be in a normal, undisturbed atmosphere. Consider the spherical Earth surrounded by a spherical atmosphere. The structure of this atmosphere can be compared to the structure of an onion. That is, consisting of many individual layers wherein each layer may be considered to be homogeneous. Since each layer supports the layer above it, the pressure increases as one moves downward in the atmosphere (just as in an ocean), and since the density is proportional to the pressure, the density of the atmosphere also increases as one travels towards the surface of the Earth. This change in density causes a light ray to change its direction of travel as it passes through the Earth's atmosphere. A change in the direction of travel of a light ray under these circumstances is described by saying that the ray has been "refracted." This refraction occurs only when a ray is passing through matter which has changes in its density. The amount of bending depends

upon the change in density between layers and upon the angle between the ray and the layers. A ray which enters a layer perpendicularly is not refracted even if the density changes. In any event, in the case of a normal atmosphere, the layers are regular and the path of a ray may be calculated with high accuracy. At the Observatory such calculations are made for every single observation and the resulting bending is called the "normal refraction." The final direction in which a ray from a star is traveling when it gets to a telescope (or to an eye for that matter), is the direction from which the starlight seems to come and this direction gives the "position" of the star. Obviously, this position is not the true position and therefore one must correct for the refraction effect. The amount of the normal refraction varies with ground level temperature and pressure as well as with the position of a celestial object with respect to the zenith. In general, the greater the distance from the zenith the greater the refraction. Looking straight up, at the zenith, the normal refraction is zero since the rays are then perpendicular to the layers of equal density. Incidentally, a line connecting points in the atmosphere which have the same density is called an isopycnic. This is analogous to an isotherm which connects points having the same temperature, or to an isobar connecting points of equal pressure. Perhaps a more familiar analogy would be the contour lines which connect points of equal elevation.

Now we can consider what happens if the atmosphere is not normal. To help simplify the situation, we may assume that over a small area of the Earth's surface, the curved layers of the normal atmosphere may be considered to be plane and parallel to the surface. When local, low-level structural changes of the atmosphere are induced by heat sources, these layers of equal density may "tilt." It is precisely this tilting which causes the anomalous refraction. It is called "anomalous" because normally the layers should be plane and parallel and not tilted. A tilt represents an anomalous or abnormal situation. In addition to the tilt effect, heat sources may also change the value of the local density of the air. This will also change the situation, but for the present this possible additional effect will be neglected. In any event we take the "total refraction" to be the sum of the normal and anomalous refraction, and it is by this amount that an observation must be corrected. The anomalous portion of the total refraction presents a serious problem because realistically it cannot be calculated like normal refraction. There are too many variables. That is, the amount of solar energy received by the buildings during the day, the heat or air conditioning usage by individuals or groups, the heat capacity of the various buildings, the geometric configuration of the heat sources, and so on. In addition, the direction and the speed of the wind are crucial parameters which, for a given set of heat sources, determine the amount and direction of the anomalous refraction. The amount of the anomalous refraction depends upon the average angle of tilt of the isopycnics, the thickness of the region within which the tilts occur and the change of the density within this region. A good approximation is given by the simplified formula:

Anomalous Refraction = Constant x Average Tilt Angle x Thickness

Compared to the amount of normal refraction, the anomalous refraction is not large. However, compared to the current observational accuracy and the required quality of the astronomical data, anomalous refraction can easily be a very significant contributor to the total error.

At this point it is useful to consider the size of the angular quantities which are being discussed. In other words, in the present context, what is "large?" What is the size of the observational error? What accuracy is required? We are dealing with angles here and everyone is familiar with the concept of an angular degree. Ninety degrees make up what is called a right angle. A degree is subdivided into 60 minutes of arc, not to be confused with minutes of time. In turn, a minute of arc is subdivided into 60 seconds of arc, so that a degree contains 60 x 60 = 3600 seconds of arc and a right angle contains 324,000 seconds of arc. These quantities are written as e.g., ninety degrees = 90°, 35 minutes of arc = 35', and 25.13 seconds of arc = 25".13, and so on. To visualize what a second of arc is, consider a dime. In order to have a dime appear to be one second of arc in angular size, it would have to be observed from 1,000 feet away, but edgewise! That is a second of arc. The normal refraction at the zenith, as stated earlier, is zero, but 45° from the zenith it is about 58".5. Near the horizon, the normal refraction is about 30'. Now the error of a single observation with the Transit Circle Telescope is about 0".2, and the dime must now be placed one mile away, still looking at it edgewise. By combining multiple observations statistically, the formal error of a star position determined in this way at the Naval Observatory in Washington is about 0".04, and the dime is now five miles away, still on edge.

Who cares about such tiny angles? Well, some defense systems currently in use require accuracies in the range of 0".1 to 0".5 for their calibration accuracy. The calibrator, namely the stars, must be significantly more accurate in order to be used as a standard. That is, the calibrator must not contribute any significant additional error to the overall error of the system. This is why the accuracy now being achieved is barely meeting requirements. It should be understood that operational systems are being discussed, not future schemes or drawing board extrapolations.

From the point of view of astronomical science, higher accuracies are always needed to expand our knowledge of the universe. Even so, our request for protection has not been generated to simply satisfy our intellectual curiosity or even as a response to traditional academic desires, regardless of the very real value of such things. No, our need for protection has arisen from concern about very real and practical national requirements which can only be satisfied by the Naval Observatory. I remind you that in the United States, it is only the Naval Observatory which makes fundamental astrometric observations. For the record, may I state that the U.S. Naval Observatory is proud of the contributions it has made to astronomical science and anticipates with pride the future contributions it hopes to make.

With the foregoing as background, some typical effects of large buildings will now be exhibited and investigated.

First, a building is characterized by such things as its bulk, the area of its exterior walls and roof, building materials, R values, HVAC energy usage, and so on. From this data an estimate of the wall and roof temperatures under specific ambient conditions is derived. These ambient conditions include the outside and inside air temperatures and the angle and intensity of the incoming solar radiation with any shading effects. The contributions to the total heat from people, light, and infiltration are also included. The computer program used for the calculations is very general. It calculates the amount of solar energy incident upon each wall and upon the roof, the amount of energy reradiated, conducted through the walls, convected to the wind and stored within each wall. In this way a realistic, dynamical picture of the building as a heat source is generated.

Using the data described above, the resulting air flow is then calculated by a very sophisticated program which numerically solves the applicable equations of hydrodynamics, the so-called Navier-Stokes equations. Dr. Kodres will describe this process and also give additional details regarding the characterization of a building.

Additional input data for this program includes the direction and speed of the wind, the relative locations of the buildings and the telescope and so on. The output of this program includes the value of the density as it varies in three dimensions. From these data, cross sections of the isopycnics are then plotted. It is from these plots that one can calculate or estimate the amount of the anomalous refraction in a particular direction. The entire process is time consuming and complicated. This is because of the scientific rigor of the physics used and the completeness of the mathematical approach. The computations were carried out in part on a CRAY computer. This computer is acknowledged to be the fastest and most sophisticated machine available today. In short, the results which are being presented to you are products of the best technology available today. The Observatory recognizes its responsibilities in this serious matter, and it has conscientiously made every effort to properly derive and interpret the data presented to you today. For example, the use of the full Navier-Stokes equations complicates the analysis greatly, but these are the rigorous equations which describe the situation. Anything else is, by definition, an incomplete description.

First, let's consider a single building. For purposes somewhat parallel to, but essentially independent of the present hearing, a particular proposed Planned Unit Development has been investigated in some detail. In this case the plot depicts the isopycnics as they occur in the East-West plane. The building, in this case, is essentially West of the Transit Circle telescope. The wind is taken to be from the West at 2 m/s (~4 mph). The time is a late afternoon in July. The tilt of the isopycnics is obvious. Using the formula given earlier, one calculates an anomalous refraction (when looking straight up) of about $0\overset{''}{.}1$ in this case. This is 200% of the standard error of the Transit Circle, $0\overset{''}{.}04$, mentioned earlier.

We are not dealing with a single building, however, and, therefore, we now consider the effects of the large buildings currently located on Wisconsin Avenue. About 32 buildings, ranging in location from the 1800 block of Wisconsin Avenue up to the intersection of Calvert Street and

Wisconsin Avenue, were included in the calculation. Here I will show the results of the calculations made assuming a SW wind and WNW wind, for the same time as the preceding example. In the case of the SW wind, the anomalous refraction (again looking straight up) is estimated, from the plotted isopycnics, to be about 0".05. With the wind from the WNW the estimated anomalous refraction drops to around 0".015. Since, at the present time, the largest buildings are located more to the SW of the telescope, the difference between these two results is exactly what one would expect, and thus gives great confidence in the correctness of our calculations. It is evident that we already have a problem when the wind is from the SW. Of course, if even larger buildings were placed to our SW, the problem would become even worse. However, to illustrate the virtue of our proposed overlay district, consider the case of a WNW wind with additional development more directly West and Northwest of the telescope. By "additional development" is meant that which could occur under present zoning, including the PUD process. The anomalous refraction now rises to about 0".3. On the other hand, if one applies the overlay concept, then the anomalous refraction increases to only about 0".06.

In order to present our case to you it has been necessary to discuss many concepts and effects which surely have never been an element in a zoning petition before. Astronomical observations are bad enough, let alone something with the unlikely name of "anomalous refraction," not to mention that verbal absurdity, "isopycnic." We are perfectly aware that such things just don't form a part of most people's daily experience. Nevertheless, these things are very real. The rigorous approach which we have used (in lieu of simple approximations) has given results which are very real. The uses to which the results of our astronomical observations are put are very real. And yes, the threat to our continued ability to satisfy national requirements is also very real.

Finally, I would like to say that the methods and principles used by us have been questioned by some. For example, the use of the Navier-Stokes equations has been criticized. This criticism is untenable and frankly would be laughed out of existence if submitted to any fluid flow expert in the world. Apropos of this, we stand ready to submit our scientific results to any acknowledged independent expert, and incidentally, Dr. Kodres and I plan to submit a paper on our results to an appropriate learned journal for judgment by our peers. It must be made known that to date, none of our disparagers has made a single calculation of a single isopycnic much less the resulting refraction. On occasion some very simplified building models have been calculated by them on a home, personal computer. Such calculations may suffice for crude, "back of the envelope" estimations, but we believe that the Zoning Commission and interested citizens deserve better. We have given this problem our best scientific "shot," and we request your help in resolving the serious problems which our scrupulous calculations have so clearly demonstrated.

Appendix B

Computer Program to Simulate the Thermal Characteristics of the Walls and Roof of Buildings

by
Cynthia H. Ruf

A computer program was developed at the Naval Civil Engineering Laboratory to determine the temporal and spacial variation in building wall and roof temperatures. The program, written in BASIC, solves the finite difference approximation of the energy equation governing heat transfer to and through the building walls.

The program considers the amount of radiation incident upon the building, taking into account the angle of the sun's rays and the shading imposed by the angle of the rays. It also considers the amount of energy reradiated, conducted through the wall, convected to the wind, and stored within the wall as internal thermal energy. The simulation has the capability to vary the thermal resistance of the wall in order to determine the sensitivity of wall temperatures to wall construction. This program also allows the user to vary the convection film coefficient in order to examine the sensitivity of wall temperatures to wind speed.

This Appendix is the user's guide to the program. In addition, the BASIC listing and typical output are provided.

USER'S MANUAL

A BASIC computer program was developed to calculate building skin temperatures due to solar loads. This program was specifically developed to determine these temperatures in order to analyze the thermal interference generated by a building. The program was developed for a specific site and therefore is not particularly user friendly or interactive. However, with the background information presented here, the user should be able to modify the necessary inputs and design parameters for any new situation.

The program was developed from segments of an existing BASIC program which contained extensive solar calculations. These calculations were modified and used in conjunction with additional heat transfer calculations to determine the building skin temperatures.

In general, the program calculates the total solar load for walls of specified orientation for one representative day of each month of the year. The program considers solar geometry, weather, location, and several variable design parameters in its calculations. The variable

design parameters allow the user to determine best/worst case scenarios for the specific problem under study.

The program is basically divided into three segments: input data, solar insolation calculations and heat transfer calculations. The program uses equations from the ASHRAE Applications Handbook (Ref 1) as well as other methods for its solar insolation calculations. The following is a brief description of the information necessary in the input data section.

The information specified in lines 100-300 are the data used to calculate direct normal insolation at the earth's surface on a clear day. 'a' is the apparent solar irradiation at air mass zero for each month; 'b' is the atmospheric extinction coefficient; and 'c' is the ratio for the diffuse radiation on a horizontal surface to the direct normal irradiation (Ref 1).

Next, the julian date for one representative day of each month is specified in DAY, line 330.

PAS, line 390, is the percent of available sunshine at the location.

The data for KTBAR, line 450, represents a measure of cloudiness and other atmospheric conditions which attenuate solar radiation at a given location. Site specific values for KTBAR can be obtained from Reference 11.

The monthly average ambient temperature is specified in TAVG, line 510. The percentage of the daily temperature range is specified in line 570, PCENT. PCENT is used along with DRANGE, line 810, which is the daily temperature range, to determine the ambient temperature throughout the day for the location.

The TILT parameter, line 630, must be set to 90 degrees for a perpendicular wall or to 0 degrees for a horizontal surface such as a roof. TILT can also be set to any intermediate value if needed.

The latitude (LAT), longitude (LONG), and time zone (TZN) for the location are specified in lines 680-700.

In addition, to specify the tilt of the surfaces, the user must also specify the orientation, i.e., N, S, SW, etc. A subroutine which calculates the solar angles for each orientation is also included in the program, lines 4000-4410.

Some other design parameters included in the program are PHO, the ground reflectance; TIN, the indoor design temperature; and HCONV, the convective heat transfer coefficient.

The wall model that is used in the program consists of layers of materials with variable resistances, including resistances for convective losses at both the inside and outside wall interfaces. The design densities, thicknesses, and specific heats of the materials incorporated in the wall model are included in the design parameters, lines 990-1070. Similarly, the appropriate resistances for the model wall layers are specified in lines 1080-1210.

Once all of the necessary information for the area to be studied is entered in the program, the program performs some preliminary calculation. The solar declination is calculated. Sunrise and sunset times are determined in line 1520 for use within the program. The daily totals for convective, conductive, solar, and radiative heat are initialized for each new day, lines 1580-1680. The ambient temperature

is calculated in line 1700 from the average ambient temperature, the daily range, and the wall outside surface temperature (TSKIN) to the ambient temperature.

The program then performs calculations, using 15-minute increments, TSTEP = 0.25, over the course of the specified day. The program calculates various solar angles, such as the azimuth and the solar incident angle, which are used to determine solar insolation. These angles, along with the previously describes input data, are then used to calculate the insolation on the building walls. The insolation calculations begin on line 2040.

Next, the program performs the heat transfer calculations beginning on line 2300. Conduction, convection, and radiation are all included in the analysis. The conductive heat transfer is determined in subroutine 5000, where the program determines the energy stored in each layer of the wall model. The convective heat transfer is determined by the skin temperature, the ambient temperature, and the design convective heat transfer coefficient, line 2330. The radiation transferred into the wall, calculated above, is the total solar insolation. The radiation transferred out from the wall is assumed to radiate to surrounding buildings with temperatures similar to those of the wall under study, and is specified in line 2350. The wall skin temperature can then be determined in subroutine 6000 where the program determines the temperature at each model wall layer interface.

The program outputs the wall temperature, in 15-minute increments throughout the day. The program will then loop to the next month. The program can also be modified to loop to the next wall orientation to complete the four (or more) walls of the structure, as well as the roof.

A sample output for the following BASIC program is included.

PROGRAM LISTING

```
10   rem  This is a basic program to calculate the skin
20   rem  temperature of a building due to solar loads.
30   rem  **********************************************
40   rem  Dimension statements
50   rem
60   dim a(12), b(12), c(12), day(12), drange(12)
70   dim pas(12), ktb(12), tavg(12), pcent(24)
80   rem  **********************************************
90   rem  Input Data Section
100  rem  **********************************************
110  rem  a = the apparent solar irradiation
120  rem  b = the atmospheric extinction coefficient
130  rem  c = the ratio of the diffuse radiation on a
140  rem       horizontal surface to the direct normal
150  rem       irradiation (from ASHRAE)
160  rem
170  data 390, 385, 376, 360, 350, 345, 344, 351, 365, 378, 387,
391
180  for q = 1 to 12
190  read a(q)
200  next q
```

```
210  rem
220  data 0.142, 0.144, 0.156, 0.180, 0.196, 0.205, 0.207, 0.201,
0.177, 0.160, 0.149, 0.142
230  for g=1 to 12
240  read b(g)
250  next g
260  rem
270  data 0.058, 0.060, 0.071, 0.097, 0.121, 0.134, 0.136, 0.122,
0.092, 0.073, 0.063, 0.057
280  for z = 1 to 12
290  read c(z)
300  next z
310  rem
320  rem  ********** day of the year **********
330  data 16,  47,  75,  106,  136, 167, 197, 228, 259, 289, 320,
350
340  for d = 1 to 12
350  read day(d)
360  next d
370  rem
380  rem  ********** percent available sunshine **********
390  data 0.75,  0.73,  0.84, 0.86, 0.89, 0.93, 0.96, 0.95, 0.92,
0.91, 0.85, 0.80
400  for W = 1 TO 12
410  read pas(w)
420  next w
430  rem
440  rem  ********** Ktbar **********
450  data 0.404, 0.435, 0.450, 0.47, 0.488, 0.514, 0.503, 0.494,
0.489, 0.475, 0.417, 0.374
460  for n = 1 to 12
470  read ktb(n)
480  next n
490  rem
500  rem  ********** ave month  ambient temps **********
510  data 32.1, 33.8, 41.8, 53.1, 62.6, 71.1, 75.3, 73.6, 66.9,
55.9, 44.7, 34.0
520  for x = 1 to 12
530  read tavg(x)
540  next x
550  rem
560  rem  ********** percent of the daily temp range *********
570  data 0.87, 0.92, 0.96, 0.99, 1.00, 0.98, 0.93, 0.84, 0.71,
580  data 0.58, 0.68, 0.76, 0.82
590  for 1 = 1 to 24
600  read pcent(1)
610  next 1
620  rem
630  rem  ********** other data **********
640  rem  the tilt must be 90 for a wall
650  rem  the tilt must be 0 for a roof
660  tilt = 90
670  rem
```

```
680  lat = 38
690  long = 77
700  tzn = 5
710  rem
720  rem  ********* direction of the wall *********
730  rem  direction = 0 for north
740  rem  direction = 1 for east
750  rem  direction = 2 for west
760  rem  direction = 3 for south
770  rem  direction = 4 for roof
790  rem
800  rem  ********** daily temperature range **********
810  data 24.2,   22.7,  22.7, 21.7, 21.0, 19.8, 18.8, 19.0, 22.6,
25.8, 28.6, 25.2
820  for i = 1 to 12
830  read drange(i)
840  next i
850  rem
860  rem ********** ground reflectance **********
870  rho = 0
880  rem
890  rem ********** design parameters ************
900  rem *********** design indoor temperature ***********
910  tin = 75
920  rem
930  rem ************ design convective heat transfer coef *****
940  hconv = 2.36
950  rem
960  rem *********** design emissivity of outer surface ************
970  eout = 0.75
980  rem
990  rem ****** design density of model wall surfaces *****
1000 dl1 = 120
1001 dl2 = 5.7
1002 dl3 = 50
1003 dl4 = 50
1010 rem
1020 rem ***** design  thickness  of model wall surfaces *****
1030 ll1 = 0.83
1031 ll2 = 0.83
1032 ll3 = 0.0625
1033 ll4 = 0.052
1040 rem
1050 rem ***** design specific heat of model wall surface *****
1060 shl1 = 0.2
1061 shl2 = 0.2
1062 shl3 = 0.2
1063 shl4 = 0.26
1070 rem
1080 rem ********* the r - values for each wall layer ****
1090 rem *** r - values can be found in ASHRAE HOF chapter 26
1100 rem
1110 rlayer = 0.11
```

```
1120 rlayer = 4.25
1130 r1 = 3.9
1140 r2 = 0.56
1150 rin = 0.685
1160 layer1 = 4
1170 layer2 = 4
1200 rem ***********************************************
1210 rtot = (layer1*rlayer1) + (layer2*rlayer2) + ri + r2
1220 rem ***********************************************
1230 rem ********* the Stefan-Boltzmann constant ******
1240 sigma = 1.74E-09
1250 rem
1260 lat = lat * 0.01745
1270 long = long * 0.01745
1280 tilt = tilt * 0.01745
1290 stilt = sin(tilt)
1300 ctilt = cos(tilt)
1310 slat = sin(lat)
1320 clat = cos(lat)
1330 rem
1340 rem ********* set the time increment *********
1350 tstep = 0.25
1360 rem ********************************************
1365 for direction = 0 to 3
1370 rem ********************************************
1380 rem ** begin the monthly calculations **
1390 rem
1400 rem for mon = 1 to 12
1410 for mon = 1 to 8 step 6
1411 rem
1420 decl = 23.45*sin(360*.01745*(284+day(mon))/365)*.01745
1430 sdecl = sin(decl)
1440 cdecl = cos(decl)
1450 rem
1460 rem ********** column headers *****************
1470 print "month", "day o the year"
1480 print mon, day(mon)
1490 if (direction = 0) then print "the wall faces north"
     else if (direction = 1) then print "the wall faces east"
     else if (direction = 2) then print "the wall faces west"
     else if (direction = 3) then print "the wall faces south"
     else if (direction = 4) then print "this is the roof"
1500 print
1510 print
1520 rem ********calculate sunrise and sunset **********
1530 x = (-tan(lat)*tan(decl))
1540 sunris = -atn(x/sqr(-x*x+1))+3.1416/2
1550 irise = 13-(sunris/.2618)
1560 iset = 12+(sunris/.2618)
1570 rem
1580 rem ******** initialize the daily totals ****************
1590 qday = 0
1600 qaday = 0
```

```
1610 ibttot = 0
1620 idttot = 0
1630 itttot = 0
1640 dayhrs = 0
1650 tqradout = 0
1660 tqcond = 0
1670 tqconv = 0
1680 rem
1690 rem ******* calculate the ambient temperature ******8
1700 tamb = (tavg(mon)+ drange(mon)/2) - pcent (irise)*drange(mon)
1701 tskin = tamb
1702 t1 = tamb
1703 t2 = tamb
1704 t3 = tamb
1705 t4 = tamb
1706 t5 = tamb
1707 t6 = tamb
1708 t7 = tamb
1709 t8 = tamb
1710 t9 = tin
1711 t10 = tin
1712 tmax = tskin
1720 rem ******** set the time limits *****************
1730 i = int(irise/tstep)
1740 n = int(iset/tstep)
1750 rem
1760 rem ********* output headers *****************
1770 print "time", "tamb", "tskin"
1780 rem
1790 rem *******************************************
1770 print "time", "tamb", "tskin"
1780 rem
1790 **********************************************
1800 rem      begin the daily calculations
1810 for j = i to n
1820 k = j*tstep
1830 xi = (12-k)*.2618
1840 rem
1850 rem ******** solar angles ***************
1860 sbeta = (clat*cdecl*cos(xi)+slat*sdecl)
1870 if (sbeta < .017) then sbeta = .017
1880 cbeta = sqr(1-sbeta*sbeta)
1890 if (cbeta = 0) then obeta = .001
1900 rem
1910 rem ******** solar azimuth, psi ***************
1920 xpsi = (cdecl*sin(xi)/cbeta)
1930 psi = atn(xpsi/sqr(-xpsi*xpsi+1))
1940 cosh = cos(.2618*(k-12+tzn)-long)
1950 test = sdecl*clat/(cdecl*slat)
1960 if ((cosh<=test) and (k<12)) then psi = 3.1416 - psi
1970 if ((cosh<=test) and (k>12)) then psi = -3.1416-psi
1980 gasub 4000
1990 cazm = co5(azm)
```

```
2000 ctheta = cbeta*cazm*stilt + sbeta*ctilt
2010 if (ctheta <= 0) then ctheta = 0
2020 rem ***************************************************
2030 rem
2040 rem      the insolation calculations
2050 rem ***************************************************
2060 rem ** direct normal insolation on a clear day
2070 idn = a (mon)/(exp(b(mon)/sbeta))
2080 rem ** total horizontal radiation for ktbar day
2090 ith = idn*(c(mon)+sbeta)* pas(mon)
2100 rem ** sky diffuse for ktbar day
2110 ids = ith*(1.39-4.03*ktb(mon)+5.53*ktb(mon)^2-3.11*ktb(mon)^3)
2120 rem ** the horizontal direct for a ktbar day
2130 idh - ith - ids
2140 rem ** direct normal for a ktbar day
2150 idn = idh / sbeta
2160 rem ** solar direct on a surface
2170 ibt = idn*ctheta
2180 rem ** solar diffuse on surface
2190 idt = ids*((1+ctilt)/2) + ith*((1-ctilt)) *rho/2
2200 rem ** total solar on surface
2210 itt = ibt + idt
2220 if (itt <=0) then itt = .00001
2230 rem
2240 rem ********** calculate new ambient temperature *******
2250 kint = int(k)
2260 tamb = (tavg(mon)+drange(mon)/2)-pcent(kin)*drange(mon)
2270 rem
2280 rem ***************************************************
2290 rem
2300 rem     the heat transfer calculations
2310 rem ***************************************************
2320 qcond = (tamb-tin)/rtot
2330 qconv = (tskin-tamb)*hconv
2340 tsurf = (tamb+tskin)/2
2350 qradout = eout*sigma*(tskin^4 - tsurf^4)
2360 qradin = itt
2370 gosub 5000
2400 rem
2410 rem ** format for output **
2420 time = kint * 100
2430 azm = azm/.01745
2440 psi = psi/.01745
2450 beta = atn(sbeta/sqr(-sbeta*sbeta+1))/.01745
2460 theta = (-atn(ctheta/sqr(-ctheta*ctheta+1))+c.1416/2).01745
2470 rem
2480 rem ** output **
2490 junk = k*100 mon 100
2500 if junk = 0 then print time, tamb, tskin
2510 rem
2520 rem ** sum the radiation for the day **
2530 ibttot = ibttot + ibt*tstep
```

```
2540 idttot = idttot + idt*tstep
2550 itttot = itttot + itt*tstep
2560 tqradout = tqradout + qradout*step
2570 tqcond = tqcond + qcond*step
2580 tqconv = tqconv + qconv*step
2590 rem
2591 gosub 6000
2592 rem
2593 if (tskin>tmax) then tmax = tskin
2594 rem
2600 next j
2610 rem ** output monthly totals **
2620 print "qradin", "qradout", "qcond", "qconv"
2630 print itttot, tqradout, tqcond, tqconv
2640 print
2650 print
2651 print "The maximum skin temperature during this month was",
tmax
2660 rem
2670 next mon
2680 rem
2685 next direction
2690 end
2700 rem
4000 rem*****************************************************
4010 rem=====================================================
4020 rem    the subroutine to calculate directions
4030 rem
4040 rem orientation       m        e      s        w
4050 rem        w =       180       90     0        90
4060 rem        w =    3.1416     1.5708   0      1.5708
4070 rem      direction = 0 for north
4080 rem      direction = 1 for east
4090 rem      direction = 2 for west
4100 rem      direction = 3 for south
4110 rem
4120 if (direction = 0) then 4130 else 4200
4130 if (k<12) then azm = (psi-3.1416)
4140 if (k>=12) than azm = (psi + 3.1416)
4150 rem
4160 return
4200 if (direction = 1) than 4210 else 4300
4210 azm = psi - w
4220 return 4230 rem
4300 if (direction = 2) then 4310 else 4400
4310 azm = psi + w
4320 return
4330 rem
4400 if (direction = 3) then azm = psi
4410 return
5000 rem ***********************************************
5010 rem
5020 rem      the conduction subroutine
```

```
5030 rem ************************************************
5040 rem
5050 cond1 = (tskin-t1)/rlayer1
5060 store1 = qradin-qradout-qconv-cond1
5070 cond2 = (t1-t2)/rlayer1
5080 store2 = cond1-cond2
5090 cond3 = (t2-t3)/rlater1
5100 store3 = cond2-cond3
5110 cond4 = (t3-t4)/rlayer1
5120 store4 = cond3-cond4
5130 cond5 = (t4-t5)/rlayer2
5140 store5 = cond4-cond5
5150 cond6 = (t5-t6)/rlayer2
5160 store6 = cond5-cond6
5170 cond7 = (t6-t7)/rlayer2
5180 store7 = cond6-cond7
5190 cond8 = (t7-t8)/rlater2
5200 store = cond7-cond8
5210 cond9 = (t8-t9)/r1
5220 store9 = cond8-cond9
5230 cond10 = (t9-t10)/r2
5240 store10 = cond9-cond10
5250 return
5260 rem ************************************************
6000 rem
6010 rem       the temperature calculations
6020 rem *************************************************
6030 dti = store1/(111*sh11*d11)
6040 tskin = tskin +dt1*tstep
6050 dt2 = store2/111*sh11*d11)
6060 t1 = t1 +dt2*tstep
6070 dt3 = store3/(111*sh11*d11)
6080 t2 = t2 +dt3*tstep
6090 dt4 = store4/(111*sh11*d11)
6100 t3 = t3 +dt4*tstep
6110 dt5 = store5/(112*sh12*d12)
6120 t4 = t4 + dt4*tstep
6130 dt6 = store6/(112*sh112*d12)
6140 t5 = t5 + dt6*tstep
6150 dt7 = store7/(112*sh12*d12)
6160 t6 = t6 + dt7*tstep
6170 dt8 = store8/(112*sh12*d12)
6180 t7 = t7 + dt8*tstep
6190 dt9 = store9/(113*sh13*d13)
6200 t8 = t8 + dt9*tstep
6210 dt10 = store10/(114*sh14*)
6220 t9 = t9 + dt10*tstep
6230 return
```

SAMPLE OUTPUT

MONTH	DAY OF THE YEAR
1	16

****

THE WALL FACES NORTH

TIME	TAMB	TSKIN
900.00	28.28	27.67
1000.00	31.01	30.52
1100.00	34.10	33.79
1200.00	37.01	37.17
1300.00	39.20	40.17
1400.00	40.65	42.35
1500.00	41.20	43.47
1600.00	40.65	43.37

THE MAXIMUM SKIN TEMPERATURE DURING THIS MONTH WAS 43.61099

QRADIN TOTAL	QRADOUT TOTAL	QCOND TOTAL	QCONV TOTAL
166.3913	2.415649E-03	129.9534	36.43517

MONTH	DAY OF THE YEAR
7	197

****

THE WALL FACES NORTH

TIME	TAMB	TSKIN
600.00	64.60	67.44
700.00	65.71	72.41
800.00	67.72	73.70
900.00	70.62	76.23
1000.00	73.96	79.98
1100.00	77.75	84.04
1200.00	81.32	88.15
1300.00	84.00	91.36
1400.00	85.78	94.70
1500.00	86.45	96.43
1600.00	85.78	96.85
1700.00	84.22	98.20
1800.00	81.77	99.56
1900.00	78.87	95.49

THE MAXIMUM SKIN TEMPERATURE DURING THIS MONTH WAS 99.55658

QRADIN TOTAL	QRADOUT TOTAL	QCOND TOTAL	QCONV TOTAL
572.7928	.228816	265.8097	306.7536

MONTH DAY OF THE YEAR
1 16
****

THE WALL FACES SOUTH

TIME	TAMB	TSKIN
900.00	28.28	38.22
1000.00	31.01	48.74
1100.00	34.10	58.51
1200.00	37.01	67.05
1300.00	39.20	73.55
1400.00	40.65	77.27
1500.00	41.20	77.69
1600.00	40.65	73.91

THE MAXIMUM SKIN TEMPERATURE DURING THIS MONTH WAS 78.05954

QRADIN TOTAL	QRADOUT TOTAL	QCOND TOTAL	QCONV TOTAL
929.9351	.1486741	362.7757	567.0099

MONTH DAY OF THE YEAR
7 197
****

THE WALL FACES SOUTH

TIME	TAMB	TSKIN
600.00	64.60	65.01
700.00	65.71	67.23
800.00	67.72	70.22
900.00	70.62	76.23
1000.00	73.96	84.24
1100.00	77.75	92.48
1200.00	81.32	99.99
1300.00	84.00	105.78
1400.00	85.78	108.99
1500.00	86.45	109.19
1600.00	85.78	106.24
1700.00	84.22	102.76
1800.00	81.77	98.88
1900.00	78.87	94.33

THE MAXIMUM SKIN TEMPERATURE DURING THIS MONTH WAS 109.6272

QRADIN TOTAL	QRADOUT TOTAL	QCOND TOTAL	QCONV TOTAL
736.0322	.4497645	271.1892	464.3918

MONTH DAY OF THE YEAR
1 16
****

THE WALL FACES WEST

TIME	TAME	TSKIN
900.00	28.28	27.67
1000.00	31.01	30.52
1100.00	34.10	33.79
1200.00	37.01	37.17
1300.00	39.20	43.48
1400.00	40.65	51.28
1500.00	41.20	58.26
1600.00	40.65	61.70

THE MAXIMUM SKIN TEMPERATURE DURING THIS MONTH WAS 61.70818

QRADIN TOTAL	QRADOUT TOTAL	QCOND TOTAL	QCONV TOTAL
402.7702	2.352482E-02	248.3496	154.3973

MONTH DAY OF THE YEAR
7 197
****

THE WALL FACES WEST

TIME	TAME	TSKIN
600.00	64.60	65.01
700.00	65.71	67.23
800.00	67.72	70.22
900.00	70.62	73.93
1000.00	73.96	78.19
1100.00	77.75	82.63
1200.00	81.32	87.04
1300.00	84.00	95.78
1400.00	85.78	107.13
1500.00	86.45	118.50
1600.00	85.78	128.23
1700.00	84.22	134.57
1800.00	81.77	135.11
1900.00	78.87	121.55

THE MAXIMUM SKIN TEMPERATURE DURING THIS MONTH WAS 135.6975

QRADIN TOTAL	QRADOUT TOTAL	QCOND TOTAL	QCONV TOTAL
1149.943	1.006868	504.2972	644.6388

MONTH DAY OF THE YEAR
1 16
****

THE WALL FACES EAST

TIME	TAMB	TSKIN
900.00	28.28	38.97
1000.00	31.01	44.87
1100.00	34.10	47.21
1200.00	37.01	46.74
1300.00	39.20	47.08
1400.00	40.65	47.76
1500.00	41.20	47.73
1600.00	40.65	46.73

THE MAXIMUM SKIN TEMPERATURE DURING THIS MONTH WAS 47.98488

QRADIN TOTAL	QRADOUT TOTAL	QCOND TOTAL	QCONV TOTAL
364.2411	1.756502E-02	161.411E	202.8114

MONTH DAY OF THE YEAR
7 197
****

THE WALL FACES EAST

TIME	TAMB	TSKIN
600.00	64.60	72.53
700.00	65.71	91.53
800.00	67.72	102.99
900.00	70.62	110.27
1000.00	73.96	113.73
1100.00	77.75	113.44
1200.00	81.32	109.80
1300.00	84.00	108.00
1400.00	85.78	107.37
1500.00	86.45	106.41
1600.00	85.78	104.71
1700.00	84.22	101.99
1800.00	81.77	98.31
1900.00	78.87	93.89

THE MAXIMUM SKIN TEMPERATURE DURING THIS MONTH WAS 114.4237

QRADIN TOTAL	QRADOUT TOTAL	QCOND TOTAL	QCONV TOTAL
1100.46	.876272	274.3008	825.2806

Appendix C

Dimensions and Locations of Buildings Included in Heat Rejection Analyses

All buildings along that portion of Wisconsin Avenue passing to the southwest of the Naval Observatory were included in these analyses. Each is identified by a number on Figure C-1. Sizes, HVAC loads, and locations of the buildings are listed on Table C-1. Recall that it is being assumed that all buildings are square. Ten feet (three meters) of height is used for each floor. The numbers in the "Location" column refer to the sectioning of Wisconsin Avenue to simplify the analyses. This was discussed previously; see Figure 22.

The "typical building" at the bottom of Table C-1 is the baseline building referred to in Table 5 and Figures 24 and 25. It is assumed to be located directly west of the 26-inch refracting telescope, and designated as No. 19 on Figure C-1.

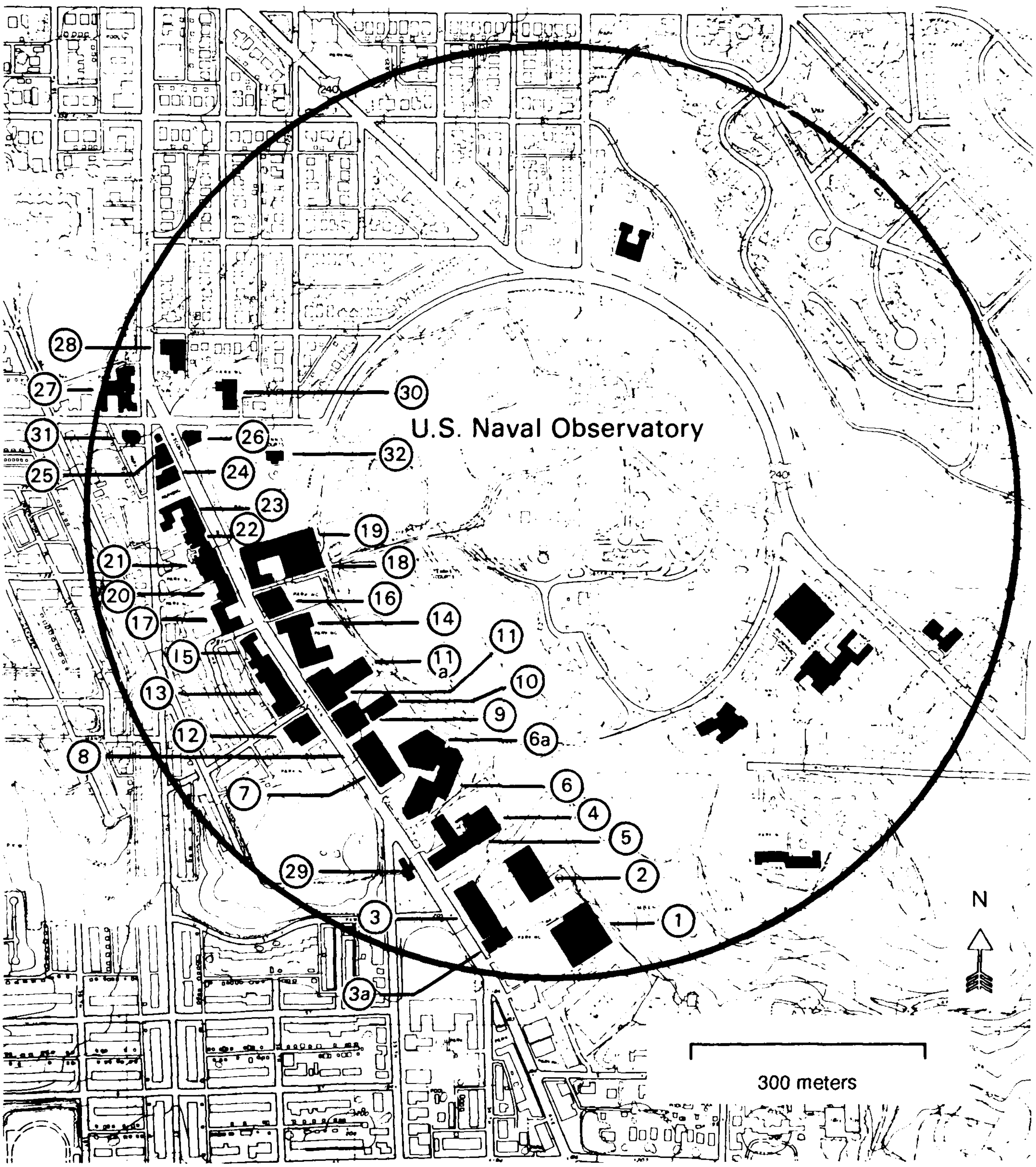


Figure C-1. Schematic of the Naval Observatory and surroundings showing the buildings included in the heat rejection calculations.

Table C-1. Dimensions and Locations of Wisconsin Avenue Buildings Included in the Heat Rejection Analyses

Building No. (see Fig C-1)	Floor Area (m^2)	Floors	Cooling (kW)	Heating (MW)	Location (see Fig 22)	Use
1	3900	1	590	435	1	Supermarket
2	10600	4	1120	1173	1	Office
3	9100	4	960	1005	1	Office
3a	700	1	100	74	1	Drug Store
4	3300	3	360	372	2	Office
5	15200	8	1150	1674	2	Hotel
6	12700	6	1580	2757	2	Office
6a	25000	7	1330	1397	3	Apartments
7	4500	4	470	496	3	Office
8	2200	2	240	248	3	Office
9,10	8800	3	920	969	4	Office
11	7800	3	820	861	4	Office
11a	8000	2	330	574	4	Apartments
12	4600	4	480	505	4	Office
13,15	4900	2	750	546	5	Commercial
14	12500	5	1320	1384	5	Office
16	3900	2	590	431	6	Commercial
17,20	6400	4	400	706	6	Apartments
18	800	2	60	90	6	Commercial
21,22,23	4900	2	750	546	7	Commercial
24,25	4900	2	750	546	7	Commercial
26	900	2	70	98	7	School
27	13700	8	860	1510	8	Apartments
28	6600	7	500	732	8	Hotel
29	700	2	40	72	8	Church
30	900	1	50	98	8	Church
31	70	1	10	7	8	Gas Station
32	700	2	100	72	8	Park Building
Typical Building	12600	7	600	744	-	Apartments

DISTRIBUTION LIST

ARMY CECOM R&D Tech Lib, Ft Monmouth, NJ; HQ Europe Cmd, AEAEN-FE-U, Heidelberg, GE; POJED-O, Okinawa, Japan; R&D Cmd, STRNC-WSA (Kwoh Hu), Natick, MA
ARMY CERL CERL-ES (DL Johnson), Champaign, IL; Library, Champaign, IL
ARMY DEPOT Letterkenny, SDSLE-EN, Chambersburg, PA
ARMY EHA HSHB-ME-A, Aberdeen Proving Grnd, MD
ARMY ENGR DIST Library, Seattle, WA
ARMY EWES WESCD-P (Melby), Vicksburg, MS
CBC Code 10, Davisville, RI; Code 15, Port Hueneme, CA; Code 155, Port Hueneme, CA; Library, Davisville, RI; Tech Library, Gulfport, MS
CHINFO OI-50D (Cronk), Washington, DC
COGARD R&DC Library, Groton, CT
COMDT COGARD Library, Washington, DC
COMNAVAIRSYSCOM Code 422, Washington, DC
DOE Wind/Ocean Tech Div, Tobacco, MD
DTIC Alexandria, VA
DTRCEN Code 2834, Annapolis, MD; Code 284, Annapolis, MD; Code 4111, Bethesda, MD; Code 4120, Annapolis, MD; Code 42, Bethesda MD; Code 421.1, Bethesda, MD; Code 522, Annapolis, MD
EPA Reg III Lib, Philadelphia, PA; Reg VIII, Lib, Denver, CO
GIDEP OIC, Corona, CA
LIBRARY OF CONGRESS Sci & Tech Div, Washington, DC
MARITIME ADMIN MMA, Library, Kings Point, NY
NAS Code 6234 (C Arnold), Point Mugu, CA
NAVAIRDEVCEN Code 832, Warminster, PA; Code 8323, Warminster, PA
NAVAIRPROPCEN CO, Trenton, NJ; Code PW-3, Trenton, NJ
NAVAVIONICCEN Code D/701, Indianapolis, IN
NAVCOASTSYSCEN CO, Panama City, FL; Tech Library, Panama City, FL
NAVENVIRHLTHCEN Code 44, Norfolk, VA
NAVFACENGCOM Code 00, Alexandria, VA; Code 03, Alexandria, VA; Code 03R (Bersson), Alexandria, VA; Code 03T (Essoglou), Alexandria, VA; Code 09M124 (Lib), Alexandria, VA
NAVFACENGCOM - CHES DIV. FPO-1PL, Washington, DC
NAVFACENGCOM - LANT DIV. Library, Norfolk, VA
NAVFACENGCOM - NORTH DIV. Code 04AL, Philadelphia, PA
NAVFACENGCOM - PAC DIV. Library, Pearl Harbor, HI
NAVFACENGCOM - SOUTH DIV. Library, Charleston, SC
NAVFACENGCOM - WEST DIV. Code 04A2.2 (Lib), San Bruno, CA
NAVMEDCOM NWREG, Fac Engr, PWD, Oakland, CA
NAVOCEANCOMCEN Code EES, Guam, Mariana Islands
NAVOCEANSYSCEN Code 811, San Diego, CA
NAVPGSCOL Code 1424, Library, Monterey, CA
NAVSHIPYD Code 308.3, Pearl Harbor, HI; Library, Portsmouth, NH; Norfolk, Code 411, Portsmouth, VA
NAVSTA Engrg Dir, PWD, Rota, Spain
NAVWARCOL Code 24, Newport, RI
NAVWPNSTA Earle, Code 0922, Colts Neck, NJ
NEESA Code 113M2, Port Hueneme, CA
NOAA Joseph Vadus, Rockville, MD; Library, Rockville, MD
NORDA Code 1121SP, Bay St. Louis, MS; Code 352, Bay St. Louis, MS
NRL Code 2511, Washington, DC
NUSC DET Code 5202 (S Schady), New London, CT
OCNR Code 1114SE, Arlington, VA; Code 1234, Arlington, VA
OFFICE OF SECRETARY OF DEFENSE ODDR&E, Environ & Life Sci, Washington, DC
PWC Code 101 (Library), Oakland, CA; Code 123C, San Diego, CA; Code 420, Great Lakes, IL; Library (Code 134), Pearl Harbor, HI; Library, Guam, Mariana Islands; Library, Norfolk, VA; Library, Pensacola, FL; Library, Yokosuka, Japan; Tech Library, Subic Bay, RP
SUPSHIP Tech Library, Newport News, VA
USNA Ch, Mech Engrg Dept, Annapolis, MD; Mech Engr Dept (C Wu), Annapolis, MD; Sys Engrg (Tuttle), Annapolis, MD
ARIZONA STATE UNIVERSITY Design Sci (Kroelinger), Tempe, AZ
BALLSTATE UNIVERSITY Arch Dept (Meden), Muncie, IN
CALIF MARITIME ACADEMY Library, Vallejo, CA
CALIFORNIA INSTITUTE OF TECHNOLOGY Environ Engrg Lib, Pasadena, CA
CITY OF LIVERMORE Dackins, PE, Livermore, CA
CORNELL UNIVERSITY Library, Ithaca, NY
DRURY COLLEGE Physics Dept, Springfield, MO
FRANKLIN RSCH CEN Library, Norristown, PA
INSTITUTE OF MARINE SCIENCES Library, Port Aransas, TX

IOWA STATE UNIVERSITY Arch Dept (McKrown), Ames, IA
KEENE STATE COLLEGE Sci Dept (Cunningham), Keene, NH
LAWRENCE LIVERMORE NATL LAB Plant Engrg Lib (L-654), Livermore, CA
LEHIGH UNIVERSITY Linderman Library, Bethlehem, PA
MAINE Energy Rscs Ofc, Augusta, ME
MAINE MARITIME ACADEMY Lib, Castine, ME
MICHIGAN TECH UNIVERSITY CE Dept (Haas), Houghton, MI
MIT CE Dept (Harleman), Cambridge, MA; Engrg Lib, Cambridge, MA; Lib, Tech Reports, Cambridge, MA
MONTANA Energy Offc (Anderson), Helena, MT
NATL ACADEMY OF SCIENCES NRC, Naval Studies Bd, Washington, DC
NEW HAMPSHIRE Gov Energy Ofc, Asst Dir, Concord, NH
NEW YORK Energy Office, Lib, Albany, NY
NY CITY COMMUNITY COLLEGE Library, Brooklyn, NY
PURDUE UNIVERSITY Engrg Lib, W. Lafayette, IN
STATE UNIVERSITY OF NEW YORK Physio Dept, Buffalo, NY
TECH UTILIZATION K Willinger, Washington, DC
TENNESSEE TECH UNIV T. Lundy, Cookeville, TN
TEXAS A&I UNIVERSITY Civil & Mech Engr Dept (Parate), Kingsville, TX
TEXAS A&M UNIVERSITY CE Dept (Machemehl), College Station, TX; Energy Trng Div (Donaldson), Houston, TX
UNIVERSITY OF ALABAMA Dir Fac Mgmt (Baker), Birmingham, AL
UNIVERSITY OF ILLINOIS Library, Urbana, IL; Metz Ref Rm, Urbana, IL
UNIVERSITY OF NEW HAMPSHIRE Elec Engrg Dept (Murdoch), Durham, NH
UNIVERSITY OF NEW MEXICO NMERI (Falk), Albuquerque, NM
UNIVERSITY OF WISCONSIN Great Lakes Studies Cen, Milwaukee, WI
VIRGINIA INST OF MARINE SCI Library, Gloucester Point, VA
WORCESTER POLYTECH INST Mech Engrg Dept (Sullivan), Worcester, MA
ACEC RESEARCH A.J. Willman, Washington, DC
AMERICAN SYS ENGRG CORP B. Williamson, Virginia Beach, VA
APPLIED SCI ASSOC, INC White, Orlando, FL
ARCAIR CO D. Young, Lancaster, OH
BATTELLE New Eng Marine Rsch Lab, Lib, Duxbury, MA
BRITISH EMBASSY Sci & Tech Dept (Wilkins), Washington, DC
BROWN & ROOT Ward, Houston, TX
CHEMED CORP Dearborn Chem Div Lib, Lake Zurich, IL
COLUMBIA GULF TRANSMISSION CO Engrg Lib, Houston, TX
CONSOER TOWNSEND & ASSOC Schramm, Chicago, IL
CONSTRUCTION TECH LABS, INC G. Corley, Skokie, IL
DAY ZIMMERMAN/BASIL CORP Fitzgerald, Hawthorne, NV
DURLACH, O'NEAL, JENKINS & ASSOC Columbia, SC
ENERCOMP H. Amistadi, Brunswick, ME
EVALUATION ASSOC, INC MA Fedele, King of Prussia, PA
GA[illegible] INC LB Holmes, Niles, IL
GENERAL DYNAMICS D-443 (Leone), Groton, CT
JOHNSON CONTROLS, INC Trng Dept, Milwaukee, WI
JOUR OF DEF C Wallach, Ed, Canoga Park, CA
KATSURA CONSULTING ENGRS Y. Katsura, Ventura, CA
MALCOM LEWIS ASSOC ENGRS, INC M. Clerx, Irvine, CA
PHILADELPHIA ELEC CO E.D. Freas, West Chester, PA
RADIANT EQUIP CO Amo, San Andreas, CA
SARGENT & HERKES, INC JP Pierce, Jr, New Orleans, LA
SAUDI ARABIA King Saud Univ, Rsch Cen, Riyadh
SCIENCE APPS INTL CORP Alexandria, VA
SIMPSON, GUMPERTZ & HEGER, INC E Hill, CE, Arlington, MA
SRI INTL J.L. Jones, Chem Engr Lab, Menlo Park, CA
3M CO CRL Anal. (Luoma), St Pual, MN
TENNESSEE VALLEY AUTHORITY W4-C143, Knoxville, TN
TEXTRON, INC Rsch Cen Lib, Buffalo, NY
THE KLING-LINDQUIST, INC Radwan, Philadelphia, PA
TRINIDAD & TOBAGO Univ of W I, Mech Engrg Dept, St Augustine, TD
TRW INC Rodgers, Redondo Beach, CA

UNITED KINGDOM Inst of Oceanographic Sci, Lib, Wormely
UNITED TECHNOLOGIES Hamilton Std Div, Lib, Windsor Locks, CT
WESTINGHOUSE ELECTRIC CORP Library, Pittsburg, PA
FISHER, R San Diego, CA
GULATI, RIPU Rockville, MD
MERMEL, TW Washington, DC
MILLER, R.W. San Diego, CA
PADILLA, LM Oxnard, CA
PODELL, H.I. New Rochelle, NY
VAN ALLEN, B Kingston, NY

INSTRUCTIONS

The Naval Civil Engineering Laboratory has revised its primary distribution lists. The bottom of the label on the reverse side has several numbers listed. These numbers correspond to numbers assigned to the list of Subject Categories. Numbers on the label corresponding to those on the list indicate the subject category and type of documents you are presently receiving. If you are satisfied, throw this card away (or file it for later reference).

If you want to change what you are presently receiving:

- Delete - mark off number on bottom of label.
- Add - circle number on list.
- Remove my name from all your lists - check box on list.
- Change my address - line out incorrect line and write in correction **(DO NOT REMOVE LABEL).**
- Number of copies should be entered after the title of the subject categories you select.

Fold on line below and drop in the mail.

Note: Numbers on label but not listed on questionnaire are for NCEL use only. please ignore them.

Fold on line and staple.

DEPARTMENT OF THE NAVY

Naval Civil Engineering Laboratory
Port Hueneme. CA 93043-5003

Official Business
Penalty for Private Use. $300

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

BUSINESS REPLY CARD

FIRST CLASS PERMIT NO. 12503 WASH D.C.

POSTAGE WILL BE PAID BY ADDRESSEE

Commanding Officer
Code L34
Naval Civil Engineering Laboratory
Port Hueneme. California 93043-5003

DISTRIBUTION QUESTIONNAIRE

The Naval Civil Engineering Laboratory is revising its Primary distribution lists.

SUBJECT CATEGORIES

1 SHORE FACILITIES
2 Construction methods and materials (including corrosion control, coatings)
3 Waterfront structures (maintenance/deterioration control)
4 Utilities (including power conditioning)
5 Explosives safety
6 Aviation Engineering Test Facilities
7 Fire prevention and control
8 Antenna technology
9 Structural analysis and design (including numerical and computer techniques)
10 Protective construction (including hardened shelters, shock and vibration studies)
11 Soil/rock mechanics
14 Airfields and pavements

15 ADVANCED BASE AND AMPHIBIOUS FACILITIES
16 Base facilities (including shelters, power generation, water supplies)
17 Expedient roads/airfields/bridges
18 Amphibious operations (including breakwaters, wave forces)
19 Over-the-Beach operations (including containerization, material transfer, lighterage and cranes)
20 POL storage, transfer and distribution

28 ENERGY/POWER GENERATION
29 Thermal conservation (thermal engineering of buildings, HVAC systems, energy loss measurement, power generation)
30 Controls and electrical conservation (electrical systems energy monitoring and control systems)
31 Fuel flexibility (liquid fuels, coal utilization, energy from solid waste)
32 Alternate energy source (geothermal power, photovoltaic power systems, solar systems, wind systems, energy storage systems)
33 Site data and systems integration (energy resource data, energy consumption data, integrating energy systems)
34 ENVIRONMENTAL PROTECTION
35 Hazardous waste minimization
36 Restoration of installations (hazardous waste)
37 Waste water management and sanitary engineering
38 Oil pollution removal and recovery
39 Air pollution

44 OCEAN ENGINEERING
45 Seafloor soils and foundations
46 Seafloor construction systems and operations (including diver and manipulator tools)
47 Undersea structures and materials
48 Anchors and moorings
49 Undersea power systems, electromechanical cables, and connectors
50 Pressure vessel facilities
51 Physical environment (including site surveying)
52 Ocean-based concrete structures
54 Undersea cable dynamics

TYPES OF DOCUMENTS

85 Techdata Sheets
86 Technical Reports and Technical Notes
83 Table of Contents & Index to TDS
82 NCEL Guides & Abstracts
91 Physical Security

☐ None–remove my name

NCEL DOCUMENT EVALUATION

You are number one with us; how do we rate with you?

We at NCEL want to provide you our customer the best possible reports but we need your help. Therefore, I ask you to please take the time from your busy schedule to fill out this questionnaire. Your response will assist us in providing the best reports possible for our users. I wish to thank you in advance for your assistance. I assure you that the information you provide will help us to be more responsive to your future needs.

R. N. STORER, Ph.D, P.E.
Technical Director

DOCUMENT NO. ________ TITLE OF DOCUMENT: ____________________

Date: ________ Respondent Organization : ____________________

Name: ____________________ Activity Code: ____________
Phone: ____________________ Grade/Rank: ____________

Category (*please check*):

Sponsor ____ User ____ Proponent ____ Other (*Specify*) ____________

Please answer on your behalf only; not on your organization's. Please check (*use an X*) only the block that most closely describes your attitude or feeling toward that statement:

SA Strongly Agree A Agree O Neutral D Disagree SD Strongly Disagree

---

	SA	A	N	D	SD
1. The technical quality of the report is comparable to most of my other sources of technical information.	( )	( )	( )	( )	( )
2. The report will make significant improvements in the cost and or performance of my operation.	( )	( )	( )	( )	( )
3. The report acknowledges related work accomplished by others.	( )	( )	( )	( )	( )
4. The report is well formatted.	( )	( )	( )	( )	( )
5. The report is clearly written.	( )	( )	( )	( )	( )
6. The conclusions and recommendations are clear and directly supported by the contents of the report.	( )	( )	( )	( )	( )
7. The graphics, tables, and photographs are well done.	( )	( )	( )	( )	( )

Do you wish to continue getting NCEL reports? ☐ YES ☐ NO

Please add any comments (e.g., in what ways can we improve the quality of our reports?) on the back of this form.

Comments:

Please fold on line and staple

DEPARTMENT OF THE NAVY

Naval Civil Engineering Laboratory
Port Hueneme, CA 93043-5003

Official Business
Penalty for Private Use $300

Code L03B
NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CA 93043-5003